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A STUDY OF PROLONGED FASTING

BY

FRANCIS GANO BENEDICT

WASHINGTON, D. C.

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PREFACE.

The research reported in this book on the metabolism during prolonged fasting is a continuation and amplification of the investigations reported in "The influence of inanition on metabolism" (Carnegie Institution of Washington Publication No. 77, 1907).

The opportunity to conduct this series of scientific observations on a man living for 31 days without food and drinking only distilled water would have been of little value without the cooperation of a large number of scientific associates and computers. Certain co-workers kindly assumed the responsibility not only for the accumulation of the data but also for the preparation of a report of their respective findings. In this book special reports are made by Dr. H. W. Goodall on the physical condition of the subject during the fast, his subjective impressions and mental attitude toward the fast, and the microscopy of the urine and the tests for albumin; by Dr. J. E. Ash on the blood; by Dr. H. S. Langfeld on the psycho-physiology of the fast; by Dr. A. I. Kendall on bacterial intestinal flora; and by Mr. H. L. Higgins on alveolar air.

Aside from those who shared directly in the responsibility of the studies, I am indebted to numerous scientific authorities for counsel and advice, both during the experiment and during the preparation of the material for publication. Those not specifically mentioned in the text are Professors Luciani of Rome, Fano of Florence, Zuntz of Berlin, Tangl of Budapest, Tigerstedt of Helsingfors, and Lusk of New York.

In no undertaking of the Nutrition Laboratory have the concentration and the unification of resources and assistants been so intensely applied and to the whole staff of the Laboratory my warmest thanks are due. Their interest and conscientious, painstaking work alone made sure the collection of the data reported in the following pages. The labor of the final preparation of the material has fallen in no small part into the excellent hands of my editorial associates, Mr. W. H. Leslie and Miss A. N. Darling.

NUTRITION LABORATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON,
Boston, Mass., July 29, 1914.

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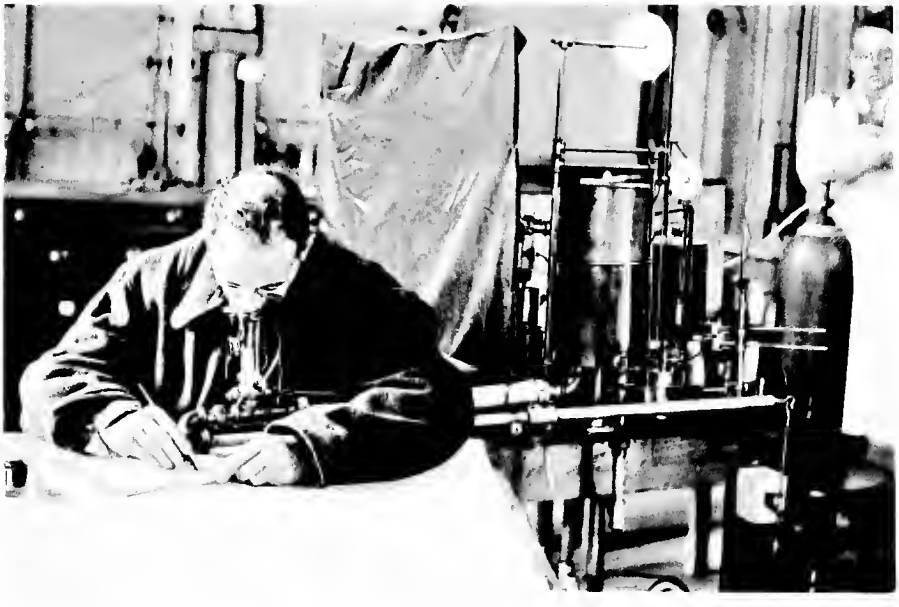


B. L. [illegible] Respiratory Ex[illegible]

INTRODUCTION.

Prolonged fasting has formed a part of religious ceremony for centuries. In early times the ascetic, in his efforts to subdue all carnal desires, believed it necessary to withdraw from the distractions of daily life and to abstain either wholly or in part from food, particularly the flesh of animals; by thus refraining from material things, he hoped to be free for spiritual thought and philosophical introspection.

Periodic fasting still constitutes a part of the rites of some religious bodies, particularly among the Hebrews, but in modern times a prolonged fast is usually undertaken either in the hope of curing or alleviating some ailment or for pecuniary gain. When a fast is resorted to for its supposed therapeutic value, information as to its history and results usually appears in one of the numerous books published by the advocates of peculiar dietetic regimes. When a fast is made by a so-called "professional faster" for pecuniary gain, the subject is exhibited to the public as an attraction to the lovers of sensational amusements. Three decades ago such exhibitions were not uncommon and in many instances the subjects consented (possibly in the hope of increasing the interest in their performance) to more or less strictly controlled observations of their fasts. Not infrequently the observations made in these professional fasting exhibitions have contributed materially to the sum of human knowledge, since there is an intense physiological interest in the vital processes during such prolonged abstinence from food.

When one considers the complex activities which make up the life of man, it will be seen that no mechanism thus far invented approximates the high organization of the vital processes which are necessary to the life of even the simplest of the warm-blooded animals; and yet sufficient experimental evidence has been accumulated to show that under normal conditions of life, and with similar routine, there are no marked variations in the life processes of normal individuals. Under varying conditions of life, however, we find that the vital activities are carried on with a greater or less intensity, this being true even of the normal individual. We thus see that there may be definite, well-established planes of vital activity. For example, when the average healthy individual is lying in bed asleep, there is no intellectual activity and no external muscular activity, the vital activity being only sufficient for simple maintenance. When he is lying quietly in bed awake, the plane of vital activity is higher, and as we study the metabolism under the varying conditions of sitting, standing, walking, and doing muscular work, we find an increasing intensity in the vital processes, with an increase in productive capacity and often an increase in efficiency.

The average normal man represents the mean between the two extremes of the emaciated, half-starved individual, disinclined to physical or mental work, and the over-fed, obese epicure, both extremes being relatively low in vital activity and in productivity. Furthermore, if we consider the metabolism under pathological conditions, we find even greater variations in the different levels of vital activity. Thus a sick person, much emaciated, lying in bed without food, and with subnormal temperature, has unquestionably a low cellular activity. On the other hand, a sick person with a high fever, even when asleep and without extraneous muscular activity, may have a greatly increased cellular activity. It will be seen, therefore, that from the standpoint of both normal physiology and pathology, a study of human individuals under different conditions and with different planes of activity is of fundamental importance.

For such study it is essential to determine the basal or fundamental metabolism, when the activities are on a low plane, to be used as a basis of comparison with other values. We may ask, then, "What is the lowest plane of vital activity which is compatible with life?" Unquestionably there have been severe pathological cases, with emaciation and muscular atrophy, in which life has been maintained at a plane far below that which can be reached by the average normal man, but it has been the prime object of most investigators in metabolism to concentrate their efforts upon securing, with normal individuals, physiological values which may withstand criticism, since these constitute the only true basis of comparison.

Taking into consideration the influence upon metabolism of muscular activity, of the ingestion of food, and the state of being awake, we may assert that the lowest metabolic plane would be found for an individual during deep sleep in bed, with complete muscular repose, and without food in the alimentary tract. As a matter of fact, with most people such a condition is usually closely approximated each day about 4 a. m. While in general no food is taken by an individual for about 10 or 12 hours during the night, yet for a considerable period of time after the evening meal nutrients are being absorbed from the ingested food materials and carried to different parts of the body, there to be oxidized or deposited. It is furthermore true that certain molecular fragments, probably acid in nature, may be absorbed from the food materials which, when carried to the various parts of the body, may actually stimulate metabolism to a greater intensity, these being the so-called katabolic stimuli. Usually the influence of the ingestion of food ceases from 6 to 8 or 10 hours after the meal, particularly if the food ingested is not protein-rich. Accordingly, for one or two hours prior to rising in the morning the normal man is probably living at his lowest metabolic plane.

As is well known, the normal body is liberally provided with reserve material, a fact which has been strikingly brought out and emphasized by Meltzer.[1] Consequently there is always a plethora of available material stored in the body for drafts in emergencies. In the normal life of man, the demands for nutrition are usually met by periodic feeding. When the demands are not met, body reserves must be drawn upon. Under such conditions it is of particular interest to note what kind of body-material is first used, the rapidity of its depletion, and the proportions of the various body constituents disintegrated as the drafts continue. It is to study these problems that observations are made upon fasting individuals. Furthermore, since many prominent clinicians are inclined to consider disease as closely allied to the various stages of inanition, data secured in a study of metabolism during fasting have a great pathological importance for interpreting the transformations of matter in disease.

PREVIOUS OBSERVATIONS OF PROLONGED FASTS.

The literature giving the results of observations during fasts has been reviewed at some length in a previous publication,[2] special emphasis being laid upon the results obtained in the earlier stages of a fast. In this publication it seems desirable to give a review of the longer fasts which have been more or less scientifically controlled and whose results can be considered as worthy of careful consideration.

The longer fasts have almost without exception been made by professional fasters who, for purposes of exhibition, have purposed going without food for a definite length of time. While such a purpose would of itself seem to show an abnormal mental condition, yet the majority of professional fasters who have been used in these experiments are for the most part physically strong, and the results may usually be looked upon as of physiological importance, not complicated by pathological lesions of any measurable magnitude. This is particularly fortunate, as many fasts reported in the daily press are undertaken as a therapeutic measure to overcome some more or less definitely localized organic or functional trouble. It is obvious, however, that such experiments are of physiological importance when the subjects are normal individuals, voluntarily fasting under strict scientific control.

Many professional fasters have made experiments of longer or shorter duration and have been studied by various investigators, but none have been so carefully studied and had so many experiments made with them and of such long duration as the Italian, Succi. Indeed, the classical work of Luciani on Succi emphasized perhaps more than any

[1]Meltzer, The Factors of Safety in Animal Structure and Animal Economy. Harvey Society Lectures, New York, N. Y., 1906–1907, p. 139.

[2]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907.

other piece of research the importance of studying prolonged fasting. In this review of the literature on long fasts, therefore, brief descriptions of the fasts made by subjects other than Succi will first be given chronologically, these being followed by descriptions of experiments made with the Italian subject. Such discussion of the results as may be necessary will be reserved for later chapters.

Observations by Paton and Stockman.[1]—An experiment was made in the fall of 1888 by Paton and Stockman on the professional faster Jacques and continued for 30 days. The body-weight was recorded, but unfortunately the urine was analyzed by the old hypobromite method. Furthermore, the values for total nitrogen output were undoubtedly disturbed by the singular fact that the subject drank from 60 to 300 c.c. of his own urine each day. Since the volume of fluid taken per day varied greatly, the body-weight fluctuated considerably, actual gains in weight being shown on some days. No feces were passed during the fast.

Observations by Lehmann, Mueller, Munk, Senator, and Zuntz.[2]—Although this research was hardly long enough to be called a study of prolonged fasting, the two experiments made by Lehmann, Mueller, Munk, Senator, and Zuntz, one on Cetti of 10 days and one on Breithaupt of 6 days, present a study of metabolism during fasting which has never been excelled in accuracy for this length of time. The experimental plan adopted in this research has been followed with but minor changes by practically all succeeding investigators. It was the intention to continue the experiments with these subjects for 20 or 30 days, but they were unavoidably shortened, owing to the condition of the subjects. The experiment on Cetti was made in March 1887, and the observations secured in this experiment were of such importance that the experimenters took advantage of an opportunity occurring in March 1888 to make an experiment with the professional faster Breithaupt. Unfortunately this experiment continued only six days. Observations were made in both experiments of the body functions, body measurements, pulse-rate, urine, feces, and respiratory exchange, and the computations and conclusions are of fundamental importance. They will be continually referred to in connection with this report.

Observations by van Hoogenhuyze and Verploegh.[3]—In a study made of the urine excreted by a professional fasting woman, van Hoogenhuyze and Verploegh gave especial attention to the creatinine content. The experiment began on June 11, 1905, and ended June 25, 1905; the

[1]Paton and Stockman, Proc. Royal Soc. of Edinburgh, 1888–1889, **16**, p. 121.

[2]Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol. u. f. klin. Med., 1893, **131**, Supp., p. 1.

[3]Van Hoogenhuyze and Verploegh, Zeitschr. f. physiol. Chem., 1905, **46**, p. 415.

following constituents of the urine were determined: Total nitrogen, urea, creatinine, uric acid, chlorides, phosphoric acid, indigo, and total acidity.

Observations by Brugsch, Mohr, Bonniger, Baumstark, and Hirsch.[1]—An experiment made on a fasting woman by Brugsch, Mohr, Bonniger, Baumstark, and Hirsch was continued from March 10 to March 25, 1906. The observations included loss in body-weight, total nitrogen, and especially acetone in the breath and acetone and β-oxybutyric acid in the urine. The ammonia-nitrogen was likewise determined. The research is of peculiar importance in that special emphasis was laid upon the relationship between acidosis and fasting.

Observations by Cathcart.[2]—An experiment, carried out by E. P. Cathcart on the professional faster Victor Beauté, with the strictest surveillance, was designed primarily to study the effect of fasting upon the partition of the nitrogen, the new methods introduced by Folin being used. The experiment was made in Glasgow in 1907 and continued 14 days. An especial study was made of the mineral matters excreted and the creatine and creatinine content of the fasting urine. An interesting complement to the fasting experiment was a study made at the end of the effect of the ingestion of the starch-cream diet of Folin, *i. e.*, a low nitrogenous diet, which was continued for a few days. During this time the uric acid and purine-nitrogen were accurately determined and the chlorine, phosphorus, and the several forms of sulphur were carefully estimated. This investigation represents the most comprehensive and exact observation of the constituents of urine passed while fasting to be found in the literature. Cathcart's associate, Charteris, published his blood findings somewhat later.[3]

Observations on Gayer.—An uncontrolled fast of 30 days was made in New York on a professional faster, Gayer, continuing from May 16 to June 14, 1910. Although the attending physicians are by no means unanimous in their opinions regarding the genuineness of the fast, the body-weights reported in a non-scientific publication[4] indicate a loss in weight not unlike that experienced in accredited fasting experiments. The accurate blood examination made by Dr. I. S. Wile[5] inspires confidence in the report of this fast.

Observations by Grafe.—Although complicated by abnormal psychical conditions, by an error on the part of the nurse in giving a rectal enema on the seventh day, and by considerable variations in muscular activity,

[1]Brugsch and Hirsch, Zeitschr. f. exp. Path. u. Therapie, 1906, **3**, p. 638; Bonniger and Mohr, *ibid.*, p. 675; Baumstark and Mohr., *ibid.*, p. 687.

[2]Cathcart, Biochem. Zeitschr., 1907, **6**, p. 109; Journ. Physiol., 1907, **35**, p. 500; Cathcart and Fawsitt, Journ. Physiol., 1907, **36**, p. 27.

[3]Charteris, Lancet, 1907, **173**, p. 685.

[4]Long, Physical Culture, August 1910, p. 190.

[5]Personal letter received from Dr. I. S. Wile, dated December 24, 1912.

the experiment of Grafe[1] with the Jaquet respiration apparatus[2] at the Medical Clinic in Heidelberg is of interest in throwing light upon the gaseous exchange and the character of the katabolism during prolonged inanition and on the ratio of carbon to nitrogen in fasting urine. Furthermore, it substantiated the observations made by Brugsch and others on the acidosis during fasting, as indicated by the excretion of acetone and β-oxybutyric acid.

Observations at Wesleyan University, Middletown, Connecticut.—With a special view to studying the drafts upon body-material during fasts of 24 to 168 hours, a lengthy series of experiments was undertaken at Wesleyan University, Middletown, Connecticut, the results of which have already been published.[3] These experiments threw much light upon the character of the drafts upon body-material during the experimental periods and showed that the organism and particularly the storage of glycogen in the body may be greatly affected by even a short fast. It has furthermore been shown that glycogen—the body-material which is first and most heavily drawn upon during fasting—may be considered as one of the most quickly realizable assets, the removal of which affects profoundly one of the safety factors of the human body.

OBSERVATIONS ON SUCCI.

Fast in Florence, 1888.—Although a short account of the experiment on Cetti made by Lehmann, Mueller, Munk, Senator, and Zuntz was published in 1887,[4] the details of their investigation did not appear until 1893,[5] and the first extensive report of a prolonged fasting investigation was that made by Luciani of the fasting experiment with Succi in Florence during the spring of 1888. The Italian report of this fast was published in 1889,[6] but the work is best known to other than Italian readers by Fraenkel's translation.[7]

Luciani's study of Succi included an extensive series of observations. Unfortunately, since the partition of the nitrogen in the urine was at that time imperfectly understood and as the gaseous exchange was studied under conditions affecting seriously the accuracy of the results, Luciani's observations are more especially of value as indications of the general body functions of a fasting man than as measurements of

[1]Grafe, Zeitschr. f. physiol. Chem., 1910, **65**, p. 21.

[2]Geheimrat W. His, on a recent visit to the Nutrition Laboratory, informed us that a fasting experiment with a professional faster, a woman, continuing 4 weeks, had been carried out not long before in his clinic in Berlin by Professor Staehelin, in which the Jaquet respiration apparatus had been used. Owing to the indisposition of the subject, the experiment was less successful than had been hoped, and Professor Staehelin's removal to Basel has indefinitely postponed the publication of the results.

[3]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907.

[4]Lehmann, Mueller, Munk, Senator, and Zuntz, Berliner klin. Woch., 1887, pp. 290 and 425.

[5]Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol. u. f. klin. Med., 1893, **131**, Supp., p. 1.

[6]Luciani, Fisiologia del digiuno; studi sull' uomo. Florence, 1889.

[7]Luciani, Das Hungern. Translation by M. C. Fraenkel. Hamburg and Leipsic, 1890.

specific chemical transformations. Succi's peculiar psychical condition, a condition which seems to be characteristic of the ascetic who subjects himself to a fast of 30 days or more, is interestingly commented upon *in extenso* by Luciani. The research as a whole was a model in plan, and as a painstaking record of cooperative research in fasting it is equaled only by the experiments of the Berlin investigators. Luciani's study unquestionably stimulated the considerable number of experiments subsequently carried out with Succi, at least 7 experiments, each continuing 20 or more days, being made with him by different investigators and in different places.

Fasts in Milan and Paris, 1886.—In reporting the results of the Florence fast, Luciani refers to two fasts said by Succi to have been made previously, one in Milan in August and September 1886, and a second in Paris in the latter part of November and the early part of December 1886. The short time between the fasts is of special interest. Little is known regarding these two fasts, but Luciani considered the records of the body-weights obtained from Succi's notebooks sufficiently reliable to include in the published report of his research and he plotted curves from them showing the loss in body-weight during the fasts.

Fast in London, 1890.—In 1890 Succi carried out a 40-day fast in London, which began on March 17.[1] Although observations were made of a number of factors during this fast, the controls were so incomplete that, aside from the body-weight, the observations have but little value at the present time. The body-weights were apparently recorded with a great degree of accuracy and form the basis of a curve which will be discussed later. No statements accompanied the records of the pulse and respiration as to whether the subject was lying, sitting, or standing, so that they can have but little significance; fluctuations in the pulse-rate give evidence of marked changes in the muscular activity at times. Strength tests were made with a hand dynamometer each day, showing practically no alteration in the strength. The axillary records of the body-temperature indicate a lowering of the temperature toward the end of the fast.

Fast in New York, 1890.—According to Succi's own statements, substantiated by newspaper reports, Succi carried out a large number of fasts which were not scientifically controlled. One of the most important of these was made in New York City about 8 months after the London fast.[2] The New York fast began on November 6, 1890, and was said to have continued 45 days. Correspondence with several of the physicians who attended this fast shows a diversity of opinion as to its authenticity. On the other hand, the body-weights recorded, if correct, indicate about the usual loss in weight, the records being 147.4

[1]British Med. Journ., 1890, pp. 764, 819, 876, 935, 996, and 1056, also p. 1444.
[2]The New York Daily Tribune, November 6, 1890, and December 21, 1890.

pounds (66.86 kilograms) at the beginning of the fast and 104.75 pounds (47.52 kilograms) at the end.

Fast in Naples, 1892.—The next scientifically controlled fast with Succi was in Naples, beginning August 7, 1892. Observations were made by Ajello and Solaro,[1] most of these being on the urine. The body-weight was likewise carefully recorded as the fast progressed, as well as the amounts of water taken. The determinations made on the urine which are of interest at this time are those of the chlorine and phosphoric and sulphuric acids. On the second day of the fast, 2 grams of feces were passed and on the eleventh day, 317 grams.

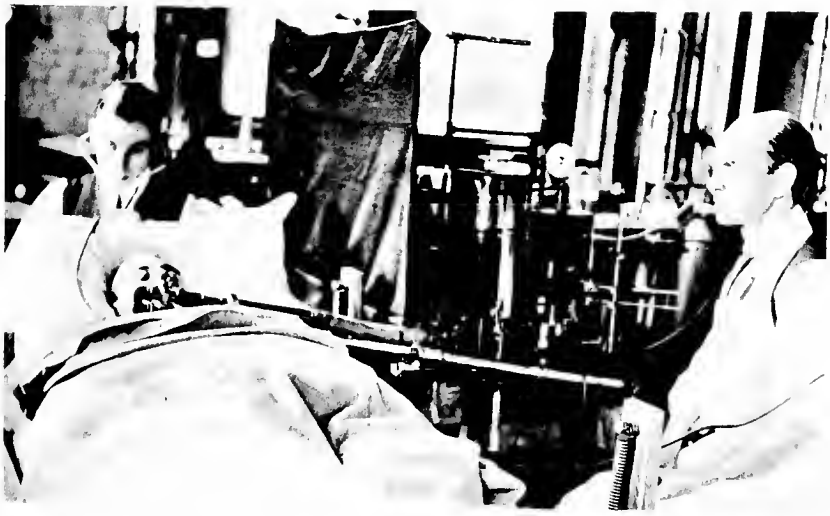
Fast in Rome, 1893.—A number of observations were made on Succi by Dutto and Lo-Monaco[2] during a 20-day fast in Rome beginning December 16, 1893. The body-weight was recorded each day, also the amount of water taken. Analyses were made of the urine excreted, these being much more complete than in any of the earlier fasts, as the nitrogen was determined by the Kjeldahl method. Determinations were also made of the acidity of the urine and the content of sulphur, ethereal sulphates, neutral sulphur, chlorine, phosphorus, sodium, and potassium.

Fast in Vienna, 1896.—The urine excreted by Succi in a 21-day fast was studied by E. and O. Freund[3] in Vienna in 1896, an extensive partition of the nitrogen being attempted for the first time. The observations as to Succi's condition, including the body-weight, were unfortunately lost.

Fast in Zurich, 1896.—During a 21-day fast of Succi in Zurich, beginning September 13, 1896, Daiber[4] studied the urine and obtained the body-weight. The body-temperature, the amount of water taken, and the chlorides in the urine were all determined with sufficient accuracy to make them of value at the present day.

Fast in Hamburg, 1904.—The last recorded experiment on Succi was made in Hamburg in March 1904. During the last 10 days of this 30-day fast, the urine was examined by Brugsch,[5] who determined the partition of the nitrogen. Special emphasis was laid upon the acidosis.

[1]Ajello and Solaro, La Riforma Medica, 1893, **2**, p. 542.
[2]Dutto and Lo-Monaco, Policlinico, 1895, **2**, p. 1.
[3]E. and O. Freund, Wiener klin. Rundschau, 1901, **15**, pp. 69 and 91.
[4]Daiber, Schweiz. Woch. f. Chem. u. Pharm., 1896, **34**, p. 395.
[5]Brugsch, Zeitschr. f. exp. Path. u. Therapie, 1905, **1**, p. 419.



C. Respiration experiment made by T. M. Carpenter, on the Universal Respiration Apparatus. These experiments were made each morning, just after the Subject left the Respiration Calorimeter, and before he stood up.

D. Weighing the Subject on the Thirty-first day of the Fast. At the right is shown the Bed on which he has just finished the Respiration Experiment; the Universaf Respiration Apparatus is shown at the extreme right.

RESEARCH ON METABOLISM IN PROLONGED FASTING AT THE NUTRITION LABORATORY.

PROBLEMS TO BE STUDIED.

In the research on metabolism during short fasting periods, which was carried out at Wesleyan University, Middletown, Connecticut, the changes incidental to the first days of fasting were, it is believed, adequately studied. On the other hand, it was desirable to supplement the earlier observations by a study of the metabolism during prolonged fasting, since many points regarding the course of the metabolism after the body had adjusted itself to the fasting condition had not been established. For instance, as the fast progresses it is important to know whether the gross metabolism alters either per kilogram of body-weight or per square meter of body-surface, also whether the acidosis is extreme or whether there is an acquired tolerance of it, and what effect the acidosis, if present, has upon the metabolism. Since the carbon, the ammonia, and the heat of combustion of the urine, also the composition of the alveolar air, give indications as to acidosis, a study of prolonged fasting should include determinations of all of these factors. In the earlier fasting study determinations were made of a number of the constituents of the urine, including total solids, nitrogen, creatine and creatinine, phosphorus, sulphur, and chlorine. In the longer research it would be necessary to elaborate these determinations, studying also the composition of the feces, should any be passed during the period. Furthermore, the relationship between the pulse-rate and the metabolism, the character of the respiration as shown by graphic records, the variations in the body-temperature, and the changes in the composition of the blood, all have sufficient significance to warrant investigation. Since muscular activity has so great an influence upon metabolism, the experiments of Zuntz on Breithaupt should be duplicated with more modern technique. Comparison should be made of the metabolism in selected periods with constant external conditions instead of with changing activity as in the earlier research, and experiments in which the subject breathed a high oxygen atmosphere would also be desirable.

The Nutrition Laboratory was especially fitted to carry out a research of this kind, being well equipped with apparatus for determining the respiratory exchange and the heat output, as well as for measuring the pulse, respiration, and muscular activity. It was therefore of fundamental importance to have ready a carefully prepared plan for studying the metabolism during prolonged fasting which could be used whenever an opportunity offered for conducting such a research. On the other hand, it was not desirable to make undue haste in beginning the

study, inasmuch as the equipment of the Laboratory was steadily being increased. The chemical technique was also being rapidly perfected, the development of the new micro methods of Professor Folin being of especial value in studying the relatively small volumes of urine excreted during prolonged fasting.

SELECTION OF SUBJECT.

While no particular effort was made to secure a subject for this research, advantage was taken of a visit to New York by Succi to confer with him. His age and his somewhat unreasonable demands for a large compensation made an arrangement with him undesirable. Furthermore, he would not have cooperated readily in the great number of tests that were included in the plan for the fasting research. A number of individuals, stimulated by the report of the earlier study, offered themselves to the Nutrition Laboratory as subjects for a fasting experiment. A large majority of these were either sufferers or imagined that they were sufferers from "nervous disease," and were therefore pathologically or psychologically undesirable. Furthermore, none of them had a clear conception of a scientifically controlled fast and of the importance of the observations which would be included in such a research. They were therefore not seriously considered.

In the spring of 1911, a letter was received from A. Levanzin of Malta, offering himself as a subject for a long fasting experiment to be carried out at the Nutrition Laboratory. The letter was voluminous, but very intelligently written, and showed an appreciation of the scientific value of such a research. As Professor Luciani, of Rome, who had made the classical study with Succi, later expressed his confidence in the ability of Levanzin to carry out a fast of this length, it seemed probable that the subject desired for the research had been found. It was subsequently learned that Professor Luciani's acquaintance with Levanzin was through correspondence only, but his recommendation went far to convince us of the desirability of attempting an experiment with this man. Accordingly an exact statement was sent A. L. of the duties involved in a research of this nature and an arrangement was entered into for him to come to Boston for the purpose. In accordance with his own proposition, the agreement was made to cover his expenses, with a bonus if the experiment was successfully completed, and every attempt was made to minimize anxiety on the part of the subject. The risk of protracted illness incidental to the journey from Malta to Boston, to the change in climate, and possibly as a result of the fasting experiment, had to be considered, and a sworn statement exonerating the Nutrition Laboratory from any responsibility for illness of more than 4 days' duration was obtained from L. before he left Malta.

PROOFS OF PHYSICAL FITNESS.

It was necessary to assure us as far as possible of the fitness of this man for the research, and he was requested to send us a physician's certificate as to his health. These proofs were supplied and were as follows:

RATNAPOORA, SLIEMA, MALTA, *10th January, 1912.*

I hereby certify that Mr. A. Levanzin, B. A., is in good health. He does not suffer from any disease and his organs are healthy.

(Signed) ROBT. SAMUT,
Professor of Physiology of Malta University.

Examination of Urine submitted by Mr. Levanzin on Feb. 10, 1912.

		Abnormal constituents.	
Quantity in 24 hours:	Unknown; taken as 1500 c.c.	Albumin	None.
Color:	Light amber.	Peptone	
Odor:	Sui generis.	Globulin	
Reaction:	Acid.	Glucose	
Specific gravity:	1018.	Acetone	
Total solids:	41.9	Blood	
Deposit:	None.	Bile	
Urea:	2.1 per cent.	Pus	
Uric acid:	0.03 per cent.	Mucus	
Chlorides:	1 per cent.	Diazo reaction	
Phosphates:	0.35 per cent.		
Indican:	Nil.		

Microscopical examination: Negative.

(Signed) ROBT. SAMUT, *Edinb.*

ROSEVILLE, 39 STRADA GHAR-ID-DUD, SLIEMA, MALTA,
January 20, 1912.

This is to certify that I have to-day physically examined Mr. Agostino Levanzin and that I have found him in good health and free from organic disease.

(Signed) JOS. S. GALIGIA, M. D.

52 Victoria Terrace, Sliema, Malta, November 7, 1911.

I hereby certify to have examined A. Levanzin, Esq., B. A., Ph. Ch., P. L., and have found him in a good state of health. The urine was normal in every respect. Specific gravity, 1025. No traces of albumen nor those of glucose, etc., have been detected. His height is 5 feet 6 inches. His skeleton and muscles are normally developed. His gross weight is 152 lbs. I am of opinion that he could undergo quite easily under ordinary circumstances a period of prolonged fasting without detriment or danger to his health, and that under ordinary conditions he is not liable to suffer from any illness that might upset the experiment or entail any hindrance to same.

I know Mr. Levanzin since many years and in fact I am his family doctor. I might add that he has already fasted for a long period without suffering any serious bad after-effects; indeed, I was astonished at his rapid recovery therefrom and return to his normal state of health. * * *

(Signed) DR. P. P. AGIUS, B. A., Ph. Ch., M. D.

AUTOBIOGRAPHICAL NOTES.

On the twenty-ninth, thirtieth, and thirty-first days of his fast at the Nutrition Laboratory, L. wrote a sketch of his life. This is reproduced verbatim, since it shows many of the interesting features of the life, education, and habits of thought of the subject.

12th of May, 1912 (29th day of my fast).

More than one hundred years ago, Gabriele Avanzino, a Sicilian, settled in Malta. Gradually the surname was corrupted into Levanzin. My mother, Lorenza Borg, living and aged about 58, descends from pure and noble Maltese blood since 400 years. Her grandfather's uncle was the famous Vincenzo Barbara, the daring sea-captain of one of the French battle-ships who was by Botta and other historians falsely accused of having betrayed Marat when he landed him to take possession of Naples on behalf of Napoleon. Barbara was the right arm of Napoleon to plot and get rid Malta from the yoke of the Knights of St. John and he was also the first Grand-Master of Free-Masons in the Island. Her grandfather was Joseph Borg, another sea-captain who came to America in the time of the Revolution, volunteered with the insurgents and fought for the American independence many battles as in his portrait that we keep he has on his breast from seven to eight medals. That is why I probably love so much freedom, independence of thought, and sympathize keenly with America.

My father, Paolo, living and aged about 68, is also the son of a sea-captain, Agostino, who was drowned when my father was only 3 years of age and so could not have a liberal education. He learned the art of ship-building which was very flourishing in those commercial times, but now being disabled from both his hands through two accidents that happened to him during his work, he is carrying a grocery-shop in a village as my mother is carrying a confectionery and toy one in the same place. They are both very honest and hard-working people and although they have sufficient property to keep them up comfortably during their old days, they do not want to give up their business as they want "to leave us something after their death." I have a sister, Teresina, 20 years, living with my mother and a married one to an engineer, Ursola, 28 years.

I was born in the Citta Cospicus of Malta, on the 23rd of May, 1872—40 years ago. At 6 years of age I went to Egypt with my mother where my father was working but came back after two years as the hot climate did not suit us. Frequented the public free-schools and at ten had my first prize—a five shilling piece—for writing the best essay against "Cruelty to Animals." Then prizes for drawing as I am very fond of art especially of music and painting. At 12 I entered the free Dockyard Schools and had several prizes. At 14 I was admitted by competitive examination as shipwright apprentice as I wished to follow my father's career, then promoted to draughtsman and then to clerk. From infancy I was always inclined to hard study and sometimes during the night I used to steal out of bed to read some interesting book because my parents did not like to see me overstrain my already weak eyes.

During the time that I served my apprenticeship in the Dockyard I published two weekly papers, successively, in Maltese the "*Habil ta Cullhadd*" (The Friend of All) and "*Is-Sengha*" (Art) to educate and enlighten the working classes that live in a very miserable condition and are totally forsaken by the Government, but both papers failed after a few months through lack of subscribers. At 17 I felt inclined to follow the ecclesiastical career to devote

myself entirely to study and oratory, that I like so much, and became a cleric, but after four years, through matter of convictions and bigoted tyranny of the superiors, I put off my black robe and entered the Lyceum to prepare myself for a professional career.

At 20 (1892) I passed my matriculation examination and took up the medical courses. At the same time I was contributing literary and political contributions to our best papers and published several poems in Italian that were very favorably appreciated by the press. I started also the publication of a University Magazine "*Lo Studente Maltese*" to stimulate the other students to contribute literary and scientific articles and I published in English and Italian a study on Shakespearean drama and some biographies of eminent Maltese personages. The paper dragged a stinty existence for two years and perished through lack of funds. At the same time I was conducting two other political papers in vernacular (Maltese), the "*Cottonera*" and the "*Habil ta'l Poplu,*" and it was one of the articles contributed to the "*Cottonera*" that provoked against me my first libel and was tried by jury.

My father was still working in Dockyard and as his foreman used to take bribes from his employees and borrow from them money that he never used to return back, and as my father did never like to satisfy him in this because he fulfilled always all his duties honestly and regularly he became his scapegoat and was always ordered to do the most dangerous and hard kind of work. Twice he was hurt, twice amputations had been operated on fingers of both hands, with peril to his life, till he became a disabled man. I protested to the superiors and they answered that they did not care a bit about it and so, at last, I published in the "*Cottonera,*" in 1895, a violent article in English in which I enumerated with details the many bribes and irregularities that were continually committed in H. M. Dockyard, signed the article and defied the Admiral Superintendent that I was ready to prove in court all my assertions. The article provoked a great scandal and the Admiral was obliged to arraign me before the criminal courts to prove my assertions. The penalty demanded against me was six months of hard labor imprisonment and a fine of £500. All my assertions were proved to the very hilt after a fierce fight and I was triumphantly acquitted, unanimously, by the jury. As I was defending the cause of thousands of leech-bled victims against a few vampires I was triumphantly carried on the shoulders of the workmen, with bengala-fires and bands playing, but the next morning my father was discharged from the Dockyard and lost his bread that was keeping us!!! I felt the shock tremendously but did not discourage myself. I put myself in correspondence with Mr. Labouchere of the "*Truth*" of London, who not only published my contributions in his very influential paper but brought the matter before Parliament, being an M. P., and fought it out very bravely. A Commission was sent to Malta and all my statements have been found to be true, my father was put to work again, and several important reforms were introduced. But after a few months my father was discharged again and forever!!! under the free and glorious banner of liberal Britain!!!

The libel took place on the 7th of August, 1895. In September of the same year, I took my degree of Bachelor of Arts from the Malta University after obtaining for three years a 50 per cent in higher mathematics, physics, natural history, philosophy, Latin, English and Italian literature and history. But my father about that time was out of work and so I had to add to my already overstraining work private lessons after my lectures, sometimes till 10 p. m., and plodded on in this very hard and anxious life for about two years in which I have followed successfully the Anatomical, General and Pathological, the Dissectional, the Physiological, the Obstetrical, the Surgical, the General

Pathology, the Chemistry, the Bacteriology, the Materia Medica, the Therapeutical and the Pharmaceutical Courses. But as at that time I was under the false impression that as I was working mentally very hard I had to eat more and more, I used to stuff myself with a lot of meat and eggs and milk and these, added to the great overstrain, shattered my nervous system down with a severe shock of neurasthenia. My professors gave me the good advice to take a long rest and to suspend my studies for a prolonged period of time. But my family could not afford that for my father was not working all the time and I had to work to live. So I took the warrant as a Pharmaceutical-Chemist after a severe examination and was employed as director of the most important pharmacy in Valletta (the capital of Malta), called "Mizzi's Dispensary." I lived there for a year and my neurasthenia got a little better through enforced rest.

But I was living away from my family and had to run into many expenses to have my meals in hotels and I was always sleeping in the pharmacy not to cross the sea late in the night and go home. So I employed myself in a pharmacy at Cospicua, very near home, and lived there for about two years. My father and mother at the same time started their business and were progressing very prosperously. My wife, Lucia, lived just opposite, and we loved each other. I married her on the 24th of April, 1900. She is the eldest daughter of Doctor G. F. Inglott, Medical Officer to Government, Knight of the Pope, and member of several literary and scientific academies and is considered as the most clever obstetrician and gynecologist in Malta, enjoying a very wide practice. So I was determined by him to start a pharmacy of my own, which I did and the result was a very successful one, but a short time after the Transvaal War broke out and as he is well conversant with the English language was called by the military authorities in charge of the Military Hospital and so all his time was absorbed in these exacting duties and could not take care any more of his private practice. This lasted for over two years and at last the pharmacy broke down and I had to remove to a wealthy country district called Birchircara.

13th of May, 1912 (30th day of my fast).

Before going to live in Birchircara I had fought two great battles—one on behalf of down-trodden and neglected Democracy and the other one advocating the maintenance in our tribunals of the Italian language that has been the means of our civilization since about 600 years. I have founded the first "Malta Trade Union," of which I was elected President, with 700 members, free schools, lectures, honest amusements, band, and carried it on successfully for some time, but political intrigue not to encourage a labor party and not to enlighten the lower class made it dwindle into nothingness and all my "love's labor was lost."

Then I went to Italy, at my own expense, for about a month, to lecture against Mr. Chamberlain's (England's Prime Minister at that time) edict that the Italian language had to be cleared off from our courts within a lapse of fifteen years. The movement had some good effect, because all the Italian press was awakened and protested loudly and vigorously and Mr. Chamberlain had to give up his Order in Council.

After creating in Birchircara a prosperous practice for my pharmacy I wished to provide for the future, and as my neurasthenia was progressing through the very close and sedentary life that I was conducting, shut up from 7 a. m. to 10 p. m., including holidays, I determined to secure a more easy career—law. I entered the legal course and succeeded to obtain a warrant. But to continue to carry on the pharmacy, to keep up my family, and to follow

a difficult university course was a very severe test on my already shattered nerves, and always under the false idea that to work very hard I had to overeat and to stuff myself with as much protein as possible, I ruined my health to such an extent that I was compelled to give up my pharmacy forever and dedicate myself to the practice of law that offered more leisure and also better prospects for me as I was and am still very popular and beloved by the people. Fortunately enough to help me at the start of my legal career, I was offered at Sliema (a beautiful summer resort in Malta) the management of a pharmacy with a very good salary with the permission to absent myself during the morning hours to go to court and plead my cases. So I went to live there and Miranda Cordelia was born, while Jolanda Beatrice was born in Birchircara. My legal practice prospered so rapidly that after a year I had to give up my pharmacy management and dedicate myself entirely to the legal career that I am still following at present.

When I thought to have fixed a solid basis for my family's subsistence I tried again to do some good work for the cause of our trampled down and utterly neglected lower classes. It has been always my ideal to enlighten them, to help them to push themselves forward as the workmen of other more progressive countries do, because although I have parted from their class my democratic soul was always with them. So I started the publication of a weekly paper entitled *"In Nahla"* (The Bee) the scope of which was to instruct in scientific, artistic, historical, and literary knowledge, as plainly and as entertainingly as possible. The effort was a brilliant success because I had immediately the greatest circulation ever attained by any paper published in any language in Malta. My wife cooperated herself very effectively because she contributed, every week, some interesting article about the rearing up of babies, hygiene, against the marriage of consumptives or between relatives, etc.

I have published in the same paper a historical novel *"Is Sahhar Falzon"* (The Wizard Falzon) in which I have treated fully and faithfully all the history of the first 60 years of the dominion of the Knights of Malta over the Island from Lisleadam to La Cassiere. My intent was to teach to the people its history not in the usual pedantic and monotonous way but enhancing it by intermingling to it the attractive episodes of chivalry and love. In the third part of the novel I have tried the *scientific* novel trying to popularize science in a delectable and easy way as I have done with history, and as Falzon was a Roman Catholic priest who was burned up alive accused of witchcraft, I developed all the up-to-date positive knowledge about psychical science of which I am an ardent and keen student. In many notes I have suggested the best books and authors and described the most authoritative experiment for those who wished to delve deeper into the matter. All the facts about Falzon were gathered through a lot of poking in our archives amongst very rare manuscripts of those past, dark, and barbarous ages. This novel was a great success because I had to publish separately in three volumes comprising over 650 large pages and the edition was sold out very rapidly.

In the *"Nahla"* I have not only tried to instruct the lower classes but I have fought hard also to defend their rights and to uplift my voice for the injustices committed against them. Twice I was tried by jury for libelous articles but twice I was triumphantly acquitted. The first time was on the 28th of October, 1909, when Antonia Azzopardi, a murderer, was hanged. The doctors in charge had executed their *post-mortem* examination so carelessly that there was doubt that the man was buried alive only one hour after the execution! I accused them of that in a very violent article, and all Malta was in a devilish row about it. The Governor ordered the Chief Medical Officer, who was responsible, to libel me and after a very hard struggle before

the jury I have succeeded to prove that there were no positive and scientific facts to prove that the executed man was dead when buried. This result provoked a new law in Malta and now instead of burying the executed men after only one hour from the execution as before, they watch them keenly for 24 hours, and as I protested also that it was barbarous to bury them in a sack after that Justice had made its cold vengeance on a creature of God against whose life she has no right at all, now they bury them in a cheap coffin.

The second trial was provoked by this fact. To communicate by means of telephone in Malta you have to pay 60 cents, and the telephones are at the Police Station. Poor people are supplied gratuitously by Government with doctors, midwives, and medicines. At a village called Zeitum a very poor woman was dying through post-partum hemorrhage. The midwife sent for the doctor for assistance as she thought the case a fatal one. The doctor happened to be in another village, and the policeman refused to call him immediately before levying the tax of the telephone. The poor woman had not the 60 cents to pay for it, and more than an hour was spent till they got them from a distant sister. When the doctor arrived there was no more hopes to save her and the poor victim of human brutality died leaving a husband and six orphans. I published a violent attack against the police accusing them of manslaughter and was libelled, but having proved to the hilt all the facts stated, I was again acquitted triumphantly by the jury.

As you can see my "*Bee*" was really a "busy" one and played very well and smartly her humanitarian and democratic mission. At the same time we did not miss to advocate, and very ardently, "Fletcherism" and the Fasting Cure for the cure of disease as also many other important dietetic reforms. Many articles were also published on behalf of the idea of an international Language. A lecture in Italian that I delivered in Malta several years ago advocating Esperanto was published in it. About 25 years ago I learned Schleyer's "Volapuk" that broke down, substituted by "Idiom Neutral," a more national system. I follow my friend Rosenberger of St. Petersburg and learned it also but had very little success. Then my dear friend's Dr. Zamenhof of Warsaw "Esperanto" came in vogue and I learned it and took up arms in favor of it very ardently. I have given in Malta free courses in the University, lectures, founded societies and succeeded also to start the first female course in the University in any branch of knowledge. Mrs. Levanzin was a great help to me in this movement and now she is the first woman in Malta to enter the University to follow a medical career. She is trying with all her efforts not only to enlighten the female classes of Malta that are yet shrouded in mediæval darkness by publishing very instructive articles but also by setting them the good example of opening for them new and prosperous careers. Esperanto had a great vogue in Malta; I, with Mrs. Levanzin, took part in the International Congress of Barcelona and there I was elected "President of the International Association of Pharmaceutical Esperantists," editor of the scientific Esperanto monthly, "*La Vocho de Farmacustoj*," and Corresponding Member of the "Colegio des Farmaceuticos" (the oldest one in the world and where the first pharmacopæia was published) after my lecture in Esperanto on the "Fungus Melitensis" by colleagues of over 30 different nationalities. Now I am advocating "Ido" or Simplified Esperanto as I find that it is easier, more logical, and cropped of all the errors and incongruities contained in Dr. Zamenhof's system.

14th of May, 1912 (31st and last day of my fast).

I have also at the same time fought hard against much ridicule and prejudice to found the first "Society of Psychical Studies and Research" in Malta of which I am President. Honorary Members are Prof. Crookes, Russell

Wallace, Lodge, Maxwell, Richet, Lombroso, Morselli, Carrington, etc. Now another battle for Science and Humanity—Fasting. About two and a half years ago, while I was over-eating, obese, neurasthenic, pessimistic and with a shattered nervous system, I chanced to read in the "*Contemporary Review*" an article about fasting. It was a flash of light that struck me vividly. It indicated to me the right path to health and happiness and I followed immediately its dictates with enthusiasm. I fasted for 8 days with very great benefit. Then I procured all the possible literature in several languages about fasting and prepared myself thoroughly for a whole year for a long and "conquest" fast. I started that on the 1st of March, 1911, and Mrs. Levanzin did the same as she had been suffering since several years from severe dyspepsia and insomnia through over-eating. She broke her fast on the 33rd day and I on the 40th with immense benefit to our health because our ailments disappeared. We continued all our usual occupations during our fast and did never feel any bad effects.

In the following August, cholera broke out in Malta and as a preventive precaution I fasted again for 12, Mrs. Levanzin for 17, and my daughters for several days each. I have cured Jolanda from a severe case of small-pox by 17 days of fasting and Miranda from a severe case of fever with 8 days. Several other friends and parents underwent the cure of fasting under my advice with marvelous effects. Enthused by these beneficial results, I determined to fix a scientific basis to it by undergoing a thorough and seriously controlled experiment under the direction of a physiologist of high repute and great experience. I submitted the case to my friend, Professor Luciani, of Physiology, of Rome, who studied Succi and published a good book on the "Physiology of Fasting," and he suggested to me to come over to Boston at the Carnegie Institution, * * * as the Institution was the best equipped in the world for such an important experiment. I took up his suggestion and crossed over 5,000 miles to undergo my fast, refusing any pecuniary remuneration, only the expenses being defrayed for it. To-day is the 31st day and last day of it, and I can simply tell you that it is a complete success. I am feeling very well, very uplifted, and I wished to prolong it further, at least to 40 days, because I do not feel yet any trace of hunger at all. But Professor Benedict thought it already very expensive and fatiguing and bid me to break it to-morrow. He only allowed me to prolong it for a day more, simply to *beat the record of the longest controlled scientific fast ever made.* During the fast I did not feel the least uncomfortable sensation except the bad taste of my coated tongue, and the catarrh and congestion of my eyes that I had at the start have nearly disappeared. I hope that a great benefit to my health shall accrue from it.

GENERAL CHARACTERISTICS OF SUBJECT.

As will be inferred from his biographical notes, L. was a propagandist with pronounced views on all subjects. He had had some legal training and was inclined to be exceedingly contentious. His chirography was excellent. He also had a good command of the English language, as well as of Italian, French, Spanish, Maltese, and Esperanto. His familiarity with the vagarious literature on fasting was astonishing, and led him to make many suggestions indicative of a mind working upon a propaganda for the supposed benefits to mankind to be derived from fasting, instead of an appreciation of the true scientific value of a prolonged fasting experiment. As an example of this, while he was unwilling to undergo a series of carefully planned strength tests, he nevertheless attempted some sensational strength tests of which he had read, such as lifting up a man and holding him suspended for a moment or two.

He was a moderately well-nourished man, but his flesh was soft and flabby. This was natural, as he was decidedly sedentary in his habits and much averse to any muscular effort. It was hoped that measurements of the fasting metabolism during muscular work could be made with this subject by having him take a moderate amount of exercise daily on the bicycle ergometer, but he absolutely refused to mount the ergometer. He said he never rode the bicycle and thought it beneath his dignity, and that although the bicycle was used in Malta, it had not been employed by his people. As L. showed so strong an objection to muscular activity, we were obliged to omit these valuable observations.

This subject called himself a vegetarian and frequently made a statement to that effect during the fast, but his practice did not wholly bear out his claim. He admitted that he ate meat in the European restaurants and on the boat during his trip to Boston, but said that it made him sick and uncomfortable, and that he was obliged to eat the meat, since he could not get the food he wished. Of considerable significance in this connection is his selection of food on the days preceding the fasting period. On his arrival in Boston he was taken to a hotel by one of the laboratory assistants and when given his choice of food from the menu, he ordered a large steak covered with onions; on other occasions he ordered salmon, pork, and lamb chops. During his stay in the hospital after the fasting experiment was over, he again called for a beefsteak. While probably not an excessive eater of meat, he was by no means a vegetarian for several weeks prior to the fast. The nitrogen found per day in the urine during the ten days preceding the fast indicated that he was living on a fairly high protein level. During the food days in Boston his diet was unrestricted and he was repeatedly told that he could have whatever he wished to eat during this preliminary period, except that it was preferred that the last meal of the day should not be excessively high in protein to avoid the long duration of the specific katabolic action of the protein.

L. left Malta the latter part of February 1912, visiting Rome, Florence, Paris, and London, on his way to Liverpool. From the latter city he came direct to Boston, arriving at the Nutrition Laboratory on the evening of April 10, 1912. Previous to his leaving for Boston, he had been asked to collect in 24-hour periods the urine passed during the trip across the ocean. While the conditions under which he would be living were necessarily abnormal, it was hoped by means of these specimens of urine to obtain some idea of the daily nitrogen outgo of the body. Specific instructions were given him as to the measurement, sampling, and preservation of the urine; as he had had a thorough training in pharmacy, he was well qualified to carry out the routine intelligently. The collection of the urine proved somewhat troublesome, as his roommates on the steamer could not appreciate the importance of the scientific test that he was to undergo.

During his stay in the laboratory, he lived the entire time in the calorimeter room, except when he was taken out for a ride or to the roof for a change of air and scene. The calorimeter room is large and well-lighted and contains several calorimeters and respiration apparatus of various models, thus permitting a considerable number of observations. The subject made his headquarters in a balcony of this room, but during the night he slept in a sealed calorimeter.

The balcony in which he spent his time when he was not in the respiration chamber or on the respiration apparatus was supplied with a comfortable sofa, chair, and desk. A bottle containing a liter of distilled water was given him, also a drinking glass, two urine jars, and a vessel for defecation. The balcony floor is 2.5 meters from the calorimeter room floor; the stairs leading to it have a rather sharp inclination, with 12 steps. (See Plate 3, figure E, page 31.) Before arranging to have him occupy this balcony, he was asked if he would be likely to become dizzy as a result of going up and down the stairs, but he replied that he was never dizzy during his fasts. Indeed, he seemed to like the idea of living in this balcony, as it gave him considerable freedom and yet made it possible to watch him. Plate 1, figure A, gives a view of him in a characteristic pose, writing at his desk in the balcony.

Throughout the fast he was under constant surveillance by various responsible members of the staff and there were nearly always two or three assistants on duty in the room. It was therefore impossible for him to leave the balcony or to obtain food without its being known at once. The watching problem in this experiment was very simple. As L. was unknown in this country, he had no friends who would attempt to bring food to him and all of those who came into communication with him had a scientific interest in having the fast carried out to the end of the time planned. While he might have drunk his urine, as did the faster Jacques, it would have been practically impossible for him to do this without its being known. Moreover, he had too much interest in the fast to do anything of the kind, and we firmly believe that if he had been surreptitiously offered food, he would have refused it.

The three days preceding the fast—the so-called preliminary period—were used to accustom the subject and the staff of assistants to the apparatus and to the general routine, in order that the program could be carried out as smoothly as possible, and without too great a demand upon the time of the physicians and co-workers who made observations upon the subject. His diet and daily life were under constant observation during this period, but he was free to choose his food and to arrange his time as he desired when no tests were being made upon him.

It was necessary to be certain that L. was physically and psychically a fit subject for the long fasting experiment. He was accordingly given several rigid physical examinations by Dr. H. W. Goodall, of the Harvard Medical School, and also underwent a psychical examination by Prof. E. E. Southard, director of the Massachusetts Psychopathic Hospital. The results of these examinations gave us every assurance that L. was a suitable subject for this long fasting experiment.

The body-weight of this subject when he reached Boston was somewhat smaller than the initial body-weight reported for his earlier fast. L. stated that his body-weight at the beginning of the previous fast was excessive and that he desired to begin this experiment with his normal body-weight. While this reasoning was scientifically correct, his small weight caused us considerable anxiety, as it was feared that he would be unable to endure a 31-day fast. Inasmuch as a fast of 7 to 10 days' duration would be of practically no value to us except as a duplication of the earlier work, every possible arrangement was made to adjust the conditions so as to prolong the fast; the subject quickly found that if he made the statement that any particularly distasteful routine or test would tend to "shorten the fast," it would be omitted. On the other hand he took an intense interest in the outcome of the experiment and had an almost religious belief in the benefits to humanity to be derived from it. He enjoyed the distinction of having so many observers studying him, and his peculiar appreciation of the scientific value of the observations enabled us frequently to induce him to waive his objections to any routine by a summary refusal to go on with that particular test unless the routine were carried out. To his credit it must be said that whatever idiosyncracies he exhibited at times, he would, after reflecting on the importance of the experiment, beg for the continuation of the complete routine.

To secure as much information as possible regarding the normal metabolism of L., he was asked to sleep inside the respiration calorimeter immediately on arriving in Boston. He was provided with a comfortable bed, air mattress, and bed clothing, the bed comparing well in size and comfort with a berth on an ocean steamer. Important data regarding the normal metabolism of this subject were thus secured for several nights before the actual fast began. Fortunately L. slept very quietly, and when not asleep he remained very quietly in the same position for long periods of time, thus greatly facilitating the accurate measurement of the metabolism.

E. L. on the Thirty-first day of the Fast, ascending the stairs of the Balcony. The picture required 20 seconds; there is no Evidence of Unsteadiness.

F. Clinical Examination by Dr. H. W. Goodall. This photograph was taken on the Thirty-first day of Fasting, upon the Balcony occupied by L. during the day.

PROGRAM FOR RESEARCH.

The many observations and the large number of co-workers and assistants made a carefully prepared program absolutely essential, so as to use the actual available time of the subject and the co-workers to the best advantage. The observations planned for each day were the weighing of the subject after he had urinated and arisen; blood tests; measurements of blood-pressure and the alveolar air; test for acetone in the breath; records of rectal temperature and of pulse-rate; the careful collection, measurement, and subsequent complete analysis of the urine; and the apportionment and measurement of the water taken. The subject entered the bed calorimeter about 8 o'clock each night, remaining there until 8 o'clock the next morning, during which time the respiratory exchange, water vaporized, and heat produced were continuously measured. He was then taken out and his respiratory exchange was observed in three experimental periods by means of the universal respiration apparatus. (See Plate 2, fig. C, page 19.) Respiration experiments were also frequently made with the subject at other times of the day and in varying body positions. The respiratory exchange when the subject was breathing an oxygen-rich atmosphere was determined several times, and a series of respiration experiments was made by Mr. T. M. Carpenter when the subject was writing. (See Plate 1, figure B, page 11.) In addition to the regular routine, there was a rigid clinical examination by Dr. Goodall every second day (see Plate 3, figure F), psychological tests were made by Dr. H. S. Langfeld, and anthropometric measurements were taken by Professor W. G. Anderson once a week. Every five or six days a complete series of photographs was made of the naked subject. (See Plates 4 and 5, p. 65.) Once a week his body was washed with distilled water, the water used being preserved and analyzed. Among the many incidental observations carried out during the experiment was a series of X-ray plates on the thirtieth day of the fast by Dr. F. H. Williams and a study of the flora in the colon on the thirty-first day by Dr. A. I. Kendall. In clear, pleasant weather the subject was taken to the roof or more frequently given a drive through the park system of Boston. The program for a typical day—that of May 7–8, 1912—appears below:

May 7.	$7^h\ 46^m$ a.m.	Bed calorimeter experiment ended.
	8 15 a.m. to $9^h\ 17^m$ a.m.	Respiration experiment (three periods.)
	9 28 a.m.	Weighed.
	10 00 a.m.	Photographs taken.
	10 30 a.m.	Blood sample taken.
	1 40 p.m.	Blood pressure tests. Alveolar air.
	3 43 p.m. to $4^h\ 14^m$ p.m.	Respiration experiment made with subject writing (two periods.)
	5 00 p.m.	Psychological tests.
	7 01 p.m. to $7^h\ 44^m$ p.m.	Respiration experiment (two periods).
	7 50 p.m.	Bath of distilled water; underwear changed.
	8 23 p.m.	Entered bed calorimeter.
	9 34 p.m.	Calorimeter experiment begun.
May 8.	7 50 a.m.	Bed calorimeter experiment ended (5 consecutive periods.)

It will be noted that the regular clinical examination did not take place on this day, as these examinations were made only on alternate days. Furthermore, no drive was taken. As will be seen from this typical program, the subject found himself fully occupied by the various observations; in all of these he took a keen personal interest.

DAILY RECORDS OF FASTING EXPERIMENT.

Although a definitely arranged program was prepared, and for the most part rigidly followed, the daily routine was varied by a large number of extraneous observations, particularly in regard to the feelings and moods of the subject, as well as observations made by coworkers. To present these adequately, it seems desirable to give them in the form of a daily record beginning with the arrival of the subject at the Nutrition Laboratory. This record will be in the nature of a "log-book," which will simply give the general history of the experiment from day to day, with no attempt to describe the technique or discuss the results.

The experimental day for most purposes ended with the completion of the respiration experiment at about $9^h\ 30^m$ a. m. The last meal was eaten at 6 p. m. on April 13, 1912; thus the true fasting period began at $9^h\ 30^m$ a. m., April 14, or about 15 hours after the last meal. In this daily history the personal observations of the subject on his experiences during the night are always given in the notes for the next day, but all events up to the moment of entering the calorimeter are recorded on the date of occurrence. While much that is said regarding the previous fasts of the subject must, from a strictly scientific standpoint, be considered as worthless, yet the trend of thought is not without interest in interpreting the mental make-up of the subject.

PRELIMINARY PERIOD.

April 10, 1912.—L. arrived at the Nutrition Laboratory about 8 p. m., coming directly from the steamer and leaving his baggage on the wharf, but bringing with him the samples of urine which he had collected for several days on his passage across the ocean. He showed himself to be heartily in sympathy with the plan of the experiment, and appeared to be a subject who would cooperate fully in the experimental routine; he placed himself entirely in our hands. As he had had no evening meal, he was sent to a hotel with one of the laboratory assistants. This meal, which was of his own selection, consisted of a large beefsteak with onions, one boiled potato, one portion chocolate ice cream, and a glass of water.

He returned to the laboratory at 10 o'clock, and then reported that he had had a very rough passage on the steamer, there being but a few hours of smooth sailing on the third day out and a few hours on the last day. On the other hand, he appeared to be in very good condition and showed no bad effects from the discomforts of the trip. He maintained that during the previous year he had lived almost exclusively on a vegetarian diet, taking occasionally milk and cheese, very rarely eggs, and no meat. On the steamer, however, the menu did not include the food he was accustomed to and he was compelled to eat

meat and "highly seasoned sauces" which he did not particularly care for. During the previous year he had been living upon one meal a day, which was eaten about noon, using the juice of an orange to satisfy his thirst when necessary. He claimed that this limited dietary had been very beneficial to his health. During the fast he wished to drink distilled water. He did not especially like it, and usually drank hot water, but since some people believed that there was nutriment in water, he wished to use distilled water so that there could be no question as to his obtaining nutriment in this way.

In his previous fasts it had been his custom to carry on his regular business and to go into court and plead his cases as usual, thus engaging in a not inconsiderable amount of muscular activity. He showed a decidedly intelligent interest in the experiment, as was indicated by his asking if the eyes should not be examined by an eye specialist, for he had found that as a fast progressed, the eyesight improved considerably, though normally he had very poor eyesight. He also thought it important to study the blood and seemed much gratified when he was told that both eye and blood tests would be made. The important role which he would play in the experiment was emphasized to him and he was shown that the efforts of the laboratory staff would be of no avail without his full cooperation. His attitude toward the experiment and understanding of the requirements showed him to be by far the most intelligent man that has ever been studied as a fasting subject.

When discussing the question of defecation during a fast, he made the statement that in some of his long fasts he had defecated only once or twice. Often he defecated shortly after the beginning of the fast and then not again until after the fast was over, but after beginning eating he defecated quite regularly. In one fast he said that he did not defecate until the twenty-seventh day.

As there was no time that evening to discuss with him at length his past history and the details of the fasting experiment, he was taken down to the calorimeter laboratory, where he urinated, removed all but his underclothing, and prepared to go into the calorimeter. The stethoscope was adjusted, and the rectal temperature taken with a clinical thermometer, which was left in the rectum three minutes. He drank a glass of water and was then placed inside the chamber of the calorimeter. After he had been shown how to use the telephone and the signal bell, a black cloth was placed before the window so that the electric light would not disturb him and the calorimeter was then sealed.

Even on this first day the subject was inclined to talk about the method of breaking his fast, saying that he was accustomed to do this by taking the juice of one or two lemons, and afterwards orange juice, to which he sometimes added sugar. As was seen later, such a method for breaking the fast proved to be disastrous to our predetermined plan of securing data after the fast.

April 11, 1912.—The calorimeter experiment for the previous night was uneventful and ended at $8^h\ 02^m$ a.m. The measurements were made in three consecutive periods, the idea being to secure observations during the latter part of the night and thus eliminate, if possible, the influence of food taken during the evening. The subject kept very quiet most of the time, and proved exceedingly tractable and intelligent. The importance of lying quietly inside the respiration chamber had been impressed upon him and we have rarely had a subject who lay so quietly for so long a time. About $5^h\ 30^m$ a. m. he telephoned to ask if everything were all right, reporting that he felt very well but had been awake for some hours. He was instructed to ring an electric bell every few minutes by pressing a small push-button inside the chamber, so as to show us that he was awake. He rang this bell regularly throughout the rest of the experiment, beginning at $5^h\ 30^m$ a. m.

When the calorimeter was opened, a strong odor of onions was apparent,

doubtless due to the fact that he had eaten beefsteak and onions the evening before. L. reported that for the first two hours after he entered the chamber he was very warm, but later became cool and slept comfortably. Since the temperature inside the calorimeter seldom varies by 0.1° C., such an observation serves excellently to illustrate the futility of placing any weight on personal impressions. The interior of the respiration chamber reminded him of his cabin on the steamer. It was impossible to obtain records of the pulse-rate for about one hour after $5^h\ 30^m$ a. m., this being due to some change in the position of the stethoscope. Later the subject was able to readjust it and the records were obtained thereafter.

When L. came out of the chamber, shortly after 8 a. m., he urinated and immediately the experiment with the universal respiration apparatus was begun. (See Plate 2, figure C, page 19.) This experiment consisted of three 15-minute periods.

Almost the entire day was spent by the subject in familiarizing himself with the experimental routines. After the respiration experiment was over, several tests of the blood pressure were made, and samples of the alveolar air taken by the Plesch and Haldane methods. Professor W. G. Anderson made a series of physical measurements and attempted the routine strength tests, but was not able to obtain these, owing to the disinclination of the subject. It did not seem advisable to complicate the program by taking photographs on this day. An examination of the blood was made, also a most careful clinical examination. L. then took a hot bath and went out with Mr. H. L. Higgins for the first meal of the day. This meal, selected à la carte, consisted of one portion of scallops and tartare sauce, one portion of roast lamb and mint sauce, two portions of mashed potato, three rolls, two portions of butter, and one portion of custard pie.

On returning to the laboratory in the afternoon, he occupied himself in writing letters and in talking with different members of the staff until about $4^h\ 30^m$ p. m., when the first series of psychological tests was made. The visual acuity test was not very successful, as L. has a very short vision and the letters used were so small that new ones had to be secured. The chief value of the test on this day was to familiarize the subject with the routine. L. continued to have a keen interest in the success of the experiment and cooperated in every way except in the strength test.

In order to make sure that the last meal of the day should contain only a small amount of protein, I went personally with him to the restaurant. His supper at this time consisted of half a grapefruit, to which he added quite a little sugar, a plate of split-pea soup (this containing practically all of the protein in the whole meal), two or three slices of bread and butter, one portion of stuffed tomatoes, one of fried sweet potatoes, another of white potatoes, one dish of strawberries and cream, and some strawberry ice cream. He returned to the laboratory about $9^h\ 30^m$ p. m. and prepared for the night in the calorimeter.

While I was with him in the afternoon and evening, L. gave me considerable information regarding his previous fasts. Although the unscientific nature of these personal impressions is recognized, it seems desirable that they should be recorded. His observations for the most part had to do with defecation, feelings of hunger, and changes in body-weight. During his fast of 40 days, which he reports as having been broken on April 10, 1911, he defecated twice during the first two days, and again, according to his remembrance, on the twenty-fifth day. The feces on the latter day consisted of a small amount of blackish or very dark brown material, with a yellowish white mucus. He defecated again the evening of the day on which he broke the fast. He

noticed that there was a large amount of gas in the intestines. His theory was that the lower portion of the bowels was clogged with feces, the rest of the intestines being filled with air, and that when he ate, the air was compressed by the food passing along the intestines, this compressed air distending the bowels and producing much colic. Thinking that it might be more advantageous for him to empty the lower bowels by an enema before beginning the fast, I suggested this to him, but he preferred not to take an enema unless it were scientifically necessary, as he believed in natural rather than forced movements. He had never had any distress from defecation or from inability to defecate such as that experienced by the subject of the fasting experiments made in Middletown, Connecticut. He also said that he usually had no hunger pains, but felt somewhat hungry. His weak point was his throat, which frequently troubled him considerably. On the twentieth day of his long fast his throat was very dry and slight traces of blood appeared. On the second day of the same fast he noticed that he was a little irritable. In the first part of a fast he was usually somewhat depressed, but not to any great degree, and after the third day he would be very happy, with no desire for food. During one of his Malta fasts he went to the table every day and watched his children eat, and, in fact, prepared delicacies for them. The first indication of a desire to break the fast was usually shown by an intense craving for an acid and it was his custom to take first a lemon and then an orange. All throughout his earlier Malta fast the color of his tongue was unnatural.

The changes in body-weight during his previous fasts were most significant. The initial weight of the 40-day Malta fast was much greater than when he came to Boston and even at the end of the fast he weighed more than he did on this date. His contention was that when a man fasts with a large amount of fatty tissue, he is "really not fasting but simply draws upon body tissue, so that the only true fasting is when a man begins the fast with a normal weight." If I had had the decision of the matter, I should have preferred to have him begin his fast with a larger amount of fatty tissue than he had. Nevertheless the results have more interest from the fact that he did not have this excessive amount of fat.

He continued to keep up his interest in the results and wished to know them from day to day, but I pointed out to him that as the fast progressed, if the results were abnormal in any way and he should be told of them, he might instinctively and unintentionally attempt to alter the conditions so as to meet the variations that we should find. It was suggested to him that he should spend all of his energy and interest on familiarizing himself with the technique and pay little attention to the results that we found, until the fast was over.

On this day he discussed extensively the writers on fasting, more especially those which would be designated as the semipopular writers. He pointed out rather naïvely that most of the writers on fasting wrote of the experiences of others, but never fasted themselves. In speaking of the fasts carried out by his wife, he said that during a prolonged fast menstruation disappeared entirely.

L. was quite impressed with the increased mental activity and power of working during a fast and maintained that any student who is to take an examination should know better than to take an excessive amount of food. He cited instances where he wrote poetry and continued his literary work during his fast and said that he was conscious of a considerably increased efficiency. According to his experience, the hours of sleep decreased somewhat, and although he began work every morning during the fast at 5 o'clock, he felt but little fatigue.

He gave no special attention to the amount of muscular exercise taken, but walked to and from his business, pleaded cases in court, went to his club, and walked about the street as usual, this exercise continuing some six or eight

hours each day, but he took no very long walks. He said that at one time, when he was being jeered at in regard to his fasting by one of his clubmates who said that he was losing strength, he suggested that they test his strength with a hand dynamometer, and he was able to show more pressure on the hand dynamometer than the man who ridiculed him. He did not believe in Succi's theory, however, that there is an increase in muscular strength during a fast.

April 12, 1912.—The records of the night observers showed that L. slept rather quietly from $9^h\ 40^m$ p. m. on April 11 until $3^h\ 33^m$ a. m. on April 12, after which time he rang the bell at intervals from 5 to 10 minutes. At 5^h30^m a. m. he telephoned that it was necessary to urinate. For this he used a 500 c.c. urine jar which had been placed inside the calorimeter the night before, but notwithstanding its size it was not sufficiently large to contain all of the urine he desired to pass. The subject reported no particular discomfort from the fact that he could not completely empty the bladder.

At noon on this day, L. went to dinner with Mr. T. M. Carpenter. His dinner, selected by himself, consisted of one portion of broiled salmon and a small quantity of green peas, two pork chops sauté, three heaping tablespoonfuls of mashed potato, a dish of sliced cucumbers and tomatoes, three small rolls, two small pieces of butter, one portion of strawberry ice cream, and two glasses of water.

At 7 p. m., he took supper, likewise with Mr. Carpenter, eating one large portion of macaroni, with apparently but little cheese in it, one large portion of fried sweet potatoes, and one large portion of fried eggplant. In addition, he ate two slices of French bread, two portions of butter, one portion of chocolate ice cream, one-half dozen macaroons, and drank five glasses of water. He seemed to enjoy this meal very much.

For the first time on this day he showed apprehension in regard to the experiment, maintaining that the number of tests made with him would tend to shorten the fast, as it required concentration on his part to cooperate with the different observers and this concentration used a certain amount of his energy. On the other hand, he suggested that a series of anthropometric measurements should be added to the tests planned for him in order to show that he was a normal individual, citing the fact that one objection that is made to professional fasters and men who fasted any great length of time is that they are not normal people intellectually and for that reason the results obtained with them could not be considered normal. He considered these measurements of the greatest importance and thought they could be obtained by taking a photograph showing the angle of the face, width of the head, etc. Since he desired them, a series of these photographs was subsequently taken.

April 13, 1912.—The records for this day show that the subject entered the calorimeter chamber at $9^h\ 40^m$ p. m., April 12, and apparently was quiet until $12^h\ 17^m$ a. m., April 13, when he began ringing the bell and continued this more or less regularly, *i. e.*, several times an hour, throughout the remainder of the night. He telephoned at $4^h\ 11^m$ a. m., and again at $5^h\ 10^m$ a. m., stating that he had slept little but felt very comfortable. He urinated at $4^h\ 11^m$ a.m., passing 595 c.c. of urine. On coming out of the calorimeter, he had considerable to say regarding the dreams that he had had; between $9^h\ 40^m$ p. m. and $12^h\ 17^m$ a. m., he slept very well without dreaming. After that period his sleep was much broken, and he had a number of dreams, one of which was accompanied by a seminal emission. He explained this by saying that his supper the night before contained too large a proportion of carbohydrates, which heated his blood and made him very uncomfortable. He almost immediately remarked that he had been very comfortable inside the chamber and, in fact, rather enjoyed being there.

A considerable number of photographs were taken of the nude subject, a procedure which evidently gave him much pleasure (see Plates 4 and 5). At $11^h\ 16^m$ a. m., he urinated and defecated, and later went out to his midday meal with Mr. Higgins. He selected pea soup with three crackers, one generous portion of fish (finnan haddie), mashed potatoes, two lamb chops, one portion of French fried potatoes, four slices of bread with butter, and one portion of strawberry ice cream and fruit syrup (college ice).

In the forenoon of the third day I told the subject that it was important that we should have some idea as to how long he expected to fast, for he had frequently made the statement that so many tests upon him would tend to shorten the fast. He was shown that a short fast would have no interest for us. He replied that he expected to fast until his body-weight fell below 100 pounds (45.4 kilograms). Inasmuch as his initial weight was 134 pounds (60.6 kilograms), he thought he would lose about a pound a day, which would make the fast approximately 30 days long.

He brought me two sealed bottles of the liquor that Succi uses in his fasts to allay the pangs of hunger at the beginning of a fast. One of these bottles he presented to the Laboratory, and asked me to keep the other for him until the fast was concluded, as he did not wish any one to say that he took the liquor and that it helped him to carry out the fast. The subject sympathized fully with the strictest surveillance and was much impressed with the fact that so many co-workers were watching and studying him.

In order to obtain an expert opinion regarding the mental state of the subject at the beginning of the fast, arrangements were made by which Dr. E. E. Southard, of the Massachusetts Psychopathic Hospital, could examine him at $3^h\ 30^m$ p. m. on this day.

L. was excessiuely voluble, continually emphasizing the importance of making measurements of his face and head, the length of the ears, and similar measurements, as he desired that a careful study should be made in order to prove that he was a normal man, and not erratic and abnormal. He also advocated with great persistency the study of the influence of fasting on the sexual organs.

At 6 p. m. he went with Mr. Carpenter to a local restaurant for the last meal before beginning the fast. This meal consisted of bananas and cream, strawberry shortcake, ice cream, and three glasses of water.

In the evening he took a hot bath, after which he was sponged with distilled water, and then put on a union suit and a pair of white stockings, both of which had been previously thoroughly washed and rinsed in distilled water and dried. The union suit absorbed the perspiration, so that a measure could be obtained of the nitrogen eliminated through the skin in the form of urea or organic nitrogenous material. After drinking a glass of water, he entered the bed calorimeter at $9^h\ 44^m$ p. m.

FASTING PERIOD.

April 14, 1912 (first day of fast).—According to the experimental records, L. rang the bell to show that he was awake from time to time during the night, there being one hour of quiet between $10^h\ 17^m$ p. m. and $11^h\ 29^m$ p. m. and another hour between $11^h\ 48^m$ p. m. and $12^h\ 49^m$ a. m., but from $2^h\ 06^m$ a. m., April 14, he rang the bell more or less regularly until $5^h\ 25^m$ a. m., when for two hours he remained quiet and was apparently asleep. At $2^h\ 06^m$ a. m. he telephoned that he was compelled to urinate. This disturbed him, as he had been sleeping very soundly. Later he suggested that if he could drink water during the day and not have to urinate during the night, he would feel more comfortable. His program was therefore arranged subsequently, to include the taking of the greater part of the water during the daytime.

When he came out of the calorimeter, he reported that he felt fairly comfortable. Some of the air had been let out of his air mattress, so that he found it easier than formerly. After the respiration experiment was over and he had washed his hands and face, he went up into the balcony and a thorough examination was made of all his clothing and baggage. This was done to make sure that nothing was hidden, such as food tablets, or alkaloids of any kind, in a form that might be sewed into his clothing, concealed in hollow books, in the tips of his shoes, or in some similar place. As he had had previous experience as a pharmacist, it seemed desirable that such precautions should be taken. Even the linings of his clothing were examined, but nothing was found, only two small cakes of soap being removed from the balcony. Besides his clothing and numerous testimonials from many of his Malta associates, a large part of his luggage consisted of so-called "fasting literature"; of particular interest to us were the materials he had collected in his visit to Succi on his way to Boston.

He had never been in the habit of using his eyes for reading or studying in the evening, but finished his work by 6 or 7 o'clock and rose early in the morning. It had been his custom to spend the evening with his family or go out for a walk, or to some place of amusement. Anticipating the tediousness of the fast, we sought to interest him in some simple game as solitaire, checkers, or whist, but he refused all of these and preferred to retire early, entering the respiration calorimeter even earlier than we had planned.

Much of the first day he talked about how well he would feel as a result of his fast, how happy he was to think that he was beginning it, how he would be relieved from the necessity of eating and drinking, so that the time he now spent in this way could be devoted to higher mental work. As he usually felt so much better during a fast, he expected that these fasting days would be among the happiest of his life. He considered that he bore the tests on this day much better than previously, showing a greater power of concentration. In the psychological test he observed that the ticking of the metronome seemed louder than in previous tests and attributed this to the fact that during fasting his hearing was always more acute. Inasmuch as this observation was made when he had omitted but one meal—the meal in the middle of the day—the weight which should be given to this observation is easily estimated. Although the weather was dull, which usually depressed him, he was perfectly certain that throughout this day he felt much better both mentally and physically than the day before. During the evening he was unusually lively and cheerful, sang and whistled quite a little, and said he felt like dancing.

Although the temperature on the balcony was 22° C., he began to complain of the cold and in the afternoon wore a blanket wrapper and bedroom slippers in addition to his regular clothing. (See Plate 1, figure A, page 11.) Subsequently he wore his heavy-weight suit of underclothes over the union suit and stockings, which had been washed in distilled water.

He said that he never used alcohol in any form and in the afternoon complained of having to drink too much water, remarking that it would shorten the fast if he drank so much, as it would wash out the salts. While there was a legitimate foundation for the statement that the distilled water might affect the salt metabolism, it was evident that L. had discovered an efficacious way of obtaining anything that he wanted by bringing forward the argument that it would "shorten the fast." It was decided that if the amount of water given him to drink caused him discomfort, he could lessen the amount. He preferred to drink only when thirsty, but that morning had taken water without feeling the need for it, and had had absolutely no hunger all the day. The water tasted much better than he had expected it to taste, as he usually disliked the taste of distilled water.

In preparing him for the respiration chamber at night, it was difficult to adjust the stethoscope so as to hear the pulse-beats through it clearly. The best results were obtained by placing the stethoscope about 1 cm. above the left nipple and 2½ cm. toward the center line of the chest. He urinated at $6^h\ 20^m$ p. m. and thought he would not urinate again during the night. By this time he had become thoroughly accustomed to the calorimeter, showing no anxiety regarding his stay in it and having the greatest confidence in those who had charge of the experiment. He entered the respiration chamber at $8^h\ 48^m$ p. m.

April 15, 1912 (second day of fast).—From the experimental records and the report of the subject, L. evidently had a very comfortable night, ringing the bell only occasionally and sleeping much better than he had any night since he had come to Boston. When he left the apparatus, he reported himself to be in excellent condition. There was no noticeable odor when the calorimeter was opened. He felt no pain or sensation of hunger, and very little thirst. During the forenoon he wrote busily and several long letters were mailed for him at noon. L. is ambidextrous, using his right hand for writing and left hand for work, that is, in taking the dynamometer test, he always used the left hand first. In conversation, he invariably led up to the discussion of the innumerable "popular" books on fasting, with which he was remarkably familiar. An ingenious argument against fasting, which he reported as having been given him by a prominent American vegetarian, was that in a fast a man became a flesh-eater, as he existed upon his own flesh.

At 4 p. m., 250 c.c. of water were taken from the 1 liter of distilled water contained in his bottle, reducing his apportionment of water to 750 c.c. Subsequently this amount was given to him daily. The rectal thermometer was used for the first time during the night of the second day of fasting, L. inserting the thermometer himself. Previous to entering the calorimeter, the subject was in unusually good spirits, singing and talking a great deal.

April 16, 1912 (third day of fast).—On coming out of the apparatus in the morning, L. said that he wore the rectal thermometer all night and suffered no distress, although at times it troubled him somewhat. The observer reported a good series of temperature measurements throughout the night. L. evidently slept more soundly than usual, ringing the bell only occasionally. No special odor was noted when the chamber was opened.

After the subject had been weighed, several photographs were taken of him nude in various positions, corresponding approximately to those taken on April 13. After he was dressed, at his request several photographs were taken of the head to show the facial characteristics. His innumerable suggestions displayed a worthy interest in the experiment, though many of them had to be disregarded.

On this day the drinking water and the urine bottle were placed on a table at the foot of the stairs leading to the balcony, the subject notifying the assistant whenever he wished water or the urine bottle. In this way all possibility of his drinking the urine, as was done by the subject of Paton and Stockman, was eliminated. Although L. was less cheerful than he was the day before, he was by no means depressed, spending a considerable part of the forenoon in writing in his diary. He was particularly cautioned against writing any of his experiences or sending out information unauthorized, as misuse would be made of the material which he gave out before the fast was completed.

We had expected that he would lie down occasionally and had provided a well-upholstered couch for his use, but he sat up practically all day. It seemed desirable, therefore, to study his metabolism in this position. Accordingly in the afternoon he came down from the balcony and a respiration experiment was

made with him in two experimental periods, while he was sitting in a comfortable chair.

During the day the subject reported that he had no bad feelings of any kind. He felt slightly irritable, but considering the confinement, he was remarkably free from this feeling of irritation, much more so than in his last fast. The disinclination to exert himself in any way which might cause the slightest strain was shown on this day when he complained that the dynamometer hurt his right hand and he did not dare to press it as hard as he would have liked to. He passed no urine from $8^h\ 05^m$ a. m., when he came out of the bed calorimeter, until $8^h\ 05^m$ p. m., just before entering the chamber, although he drank all of the 750 c.c. of distilled water, taking the last portion at $5^h\ 50^m$ p. m., when he finished the psychological tests.

In the evening, just before entering the calorimeter, he said that the rectal thermometer irritated him considerably and had kept him awake more or less the night before. He was aware of its presence every time he woke up and during the day the anus had been somewhat irritated. He asked if the temperature could not be taken every other night instead of every night, as had been planned, and the thermometer was accordingly not used on the night of April 16–17.

April 17, 1912 (fourth day of fast).—Both the experimental records and L.'s report indicate that he slept better on the night preceding this day than he had any night thus far passed in the chamber. The day was uneventful. He said that he had no great thirst and he drank the distilled water more from a sense of duty than from any desire for it. He did not leave the balcony during the day except for the psychological test at $4^h\ 50^m$ p. m. At one time during the forenoon he was seen to hold up a light man, weighing but 125 pounds (56.7 kilograms) for a few seconds. He appeared pleased with this supposedly "sensational feat" and was quite unappreciative of the caution to conserve his strength for tests of muscular strength that could be measured, tests that he had repeatedly refused to make.

On this day he wore the stethoscope most of the day, an assistant counting the pulse-rate at a distance from him and unknown to him for the greater part of the time. It was hoped that more or less continuous records of the pulse-rate could be obtained in this way. In preparing him for the calorimeter at night, I personally inserted the rectal thermometer and he reported that it did not hurt him in any way. He believed that, when putting it in himself the first night, he must have irritated the anus somewhat, thus causing the subsequent discomfort. The subject entered the calorimeter for the night at $8^h\ 19^m$ p. m.

April 18, 1912 (fifth day of fast).—The subject reported in the morning that he slept quite well during the night, but not so well as he did the night before. He thought he went to sleep about an hour after entering the calorimeter and woke up several times during the night. He said he was entirely comfortable, the rectal thermometer giving him no trouble. The spring supporting the bed had been somewhat weakened in order to obtain a greater sensitivity for the apparatus recording the muscular activity. The records show, for the most part, a remarkably quiet night, so that long calorimeter experiments of 10 or 11 hours will be perfectly comparable so far as the muscular activity is concerned. In this respect the subject was exceptionally well adapted for an experiment of this kind.

Notwithstanding the dull weather, L. said that he felt very well, with no loss of strength, headache, feeling of hunger, or of apprehension. He was not usually troubled with headache during a fast. When his measurements were taken, his height was found to be 1.707 meters. He said that his maximum weight was 14 stone or 196 pounds (88.9 kilograms). His initial weight for

the Malta fast was 12 stone and 3 pounds, or 171 pounds (77.6 kilograms). During this fast he lost 37 pounds (16.8 kilograms), and thus weighed at the end of the fast 134 pounds (60.8 kilograms). These measurements included the weight of the clothing worn and were taken with ordinary scales, but probably represent average weights.

In the evening L. talked about his work in Malta and his interest in the numerous fasting books which he had read. He became quite excited in talking of three legal cases in which he was involved in Malta, speaking with a good deal of vigor and enthusiasm. There was not the slightest evidence of his having fasted for 4½ days. After inserting the rectal thermometer, the subject entered the bed calorimeter about the usual time.

April 19, 1912 (sixth day of fast).—The subject was sleeping very soundly when the calorimeter experiment was ended and on leaving the apparatus, reported that he had had a very comfortable night. He seemed very bright and quite like himself. According to the records of the observers, the subject slept very well throughout the night until $5^h\ 30^m$ a. m., when he rang the bell intermittently for a short time. He still continued to have no discomfort, no sensations of hunger, and no apprehensions, and felt very much inclined to mental work. He said he did not expect to have such an excellent fast and seemed to be content with the progress of the experiment. On this day the subject spent considerable time in writing. To provide data for subsequent computation of the total energy transformation during the 24 hours, it seemed desirable to measure the respiratory exchange while the subject was writing. This type of experiment, which had never been attempted in this laboratory before, proved to be very successful, the subject sitting in a comfortable chair and writing as usual. (See Plate 1, figure B, page 11.)

April 20, 1912 (seventh day of fast).—When the calorimeter was opened, no odor of acetone was apparent, and no unpleasant odor of any kind. Thus far in the series of calorimeter experiments, the only unpleasant odor which has been noted was the strong smell of onions on the morning following his evening meal of beefsteak and onions. L. said that he was in excellent condition; intellectually he was very acute. He slept well throughout the night with no discomfort and rang the bell only a few times. With the sunny weather the subject's spirits rose and he reported himself as feeling very happy and uplifted; he sang at times during the morning. A barber cut his hair and beard on this day, the trimmings being saved for analysis.

After taking a bath in the evening, he entered the calorimeter. He told one of the assistants that he felt very drowsy and expected to go to sleep almost immediately.

April 21, 1912 (eighth day of fast).—On coming out of the apparatus, the subject reported that he did not go to sleep as quickly as he had expected to; he lay awake for 2 hours and also woke up in the night once or twice. He slept well, however, and had several dreams which he reported to Dr. Langfeld. L. asked if he did not have fever during the first 2 or 3 days of the fast, stating that his wife during the first days of her fast had quite a high fever. When he was told that he had had no fever he was much surprised. His theory was that "in the first days of the fast, the blood rid itself of all impurities, the burning process producing a high fever."

In the afternoon, the subject went up to the roof, using the elevator; he remained there for about 1½ hours, sitting in the sun and chatting on general subjects. He said considerable about his experience with Esperanto and about many of his Maltese customs. His voice was strong, and he seemed to be very well and bright. He came down from the roof by the elevator to the office and dictated into the dictaphone a statement regarding his feelings. The dictated report is as follows:

"I felt very bright this morning because the sun was shining very brightly and the day is so fine and so sunny that it looks very much like one of my Maltese days for which I am very desirous. This afternoon I have been on the roof of the laboratory so as to enjoy the sun, which I love so much because I was born and bred in it, and I do not feel very fatigued at all or any apprehension or any fear. I feel very hopeful that my fast will be not only a very long one but a very successful one, and I feel no pangs of hunger whatever or any other sensations in my stomach, and I think that my health is progressing because the catarrh of the head in my nose and in my pharynx before the starting of the fast has nearly disappeared and I can aspirate very easily through my nostrils, a thing which I could not do very easily before, and also I feel that my eyes are getting less congested and better. I do not feel any dizziness at all, and I have never felt it, neither when I lean down to get up something that falls from the hand; in fact, I can come down the steep stairs of my balcony apartment very easily without taking hold of the railing and without any necessity of being helped by any one. My legs feel very strong and I do not feel any numbness in them."

The subject went from the office to the calorimeter laboratory on the elevator and drank a glass of water, but did not return to the balcony, as it was almost time for the psychological tests. The rectal thermometer was used during the bed calorimeter experiment, observations being made every 10 minutes during the night.

April 22, 1912 (ninth day of fast).—On opening the calorimeter chamber no odor was noticeable. The subject reported a very comfortable night and said that he felt very well, except that he had had a bad taste in his mouth for several days. He slept very quietly, ringing the bell only three times. During the day he had visits from a number of scientific men, with whom he talked considerably. He was particularly interesting and vivacious in discussing his experiments with Professors Cannon and Folin and with Dr. Cathcart. He reported that he did not now feel so much inclined to mental work, explaining this fact on the ground that "the brain was occupied in eliminating the impurities from the blood."

April 23, 1912 (tenth day of fast).—This morning L. said that the preceding night was the best that he had had in the calorimeter. He was very quiet during the night and rang the bell but a few times. He still complained of the bad taste in his mouth.

In the afternoon a respiration experiment of two periods was made with the subject sitting in a chair. In this experiment certain abnormal values were obtained for the pulse-rate and the respiratory quotient, and Mr. Carpenter thought that there was a slight irregularity in the action of the heart. Since the man was essentially different as to his total metabolism from the day before, Dr. Goodall was asked to examine him during Dr. Langfeld's tests. Dr. Goodall noted the heart rate before, during, and after the dynamometer test, and pronounced the subject to be in an excellent condition.

L. had been less self-assertive for the week previous, much more inclined to cooperate in the experimental routine, and a little more reconciled to the fact that the observers were familiar with their technique. He was more quiet and less argumentative than formerly and was at times considerably depressed, spending much of the time in thinking of home. In conversation he seemed very intelligent and interested in everything, and by no means lethargic. He professed to have no discomfort from the rectal thermometer, although he stated frankly that he feared its use very much before coming to America. He also was becoming accustomed to the respiration chamber and did not find it at all irksome.

During the respiration experiment in the afternoon he spoke of the delightful sensation that he had in these experiments, saying that the sound of the rotary blower did not disturb him, but on the contrary it seemed soothing. This effect is not unusual with other subjects of respiration experiments, the purring sound of the blower frequently producing drowsiness, so that it is difficult for the subjects to keep awake.

April 24, 1912 (eleventh day of fast).—Although L. rang the bell but once an hour throughout the night, he maintained that he did not sleep well and consequently felt somewhat irritated when he came out of the apparatus. Although the weather was fine, he was quite depressed during much of the day. He said that it was the twelfth anniversary of his marriage, and he spent the whole day thinking of his family and his home in Malta.

In the respiration experiment in the afternoon, with the subject sitting, the nose-pieces troubled him somewhat, and he became very irritable before the experiment was finished. He was, in fact, quite intractable for a time, complaining bitterly about the rapidity with which the experiments were made and how frequently he was passed from one observer to another. In discussing the matter, he said that it was not the experiments themselves which troubled him and he did not particularly object to the respiration experiments, but that when he had finished and opened his eyes, he saw the next observer waiting for him, and he thought the tests made upon him were not far enough apart. On beginning certain of the psychological tests, he stopped and refused to go any farther, saying that he wanted to have 15 minutes' rest. He was very irritable and said that irritability was bad for him. At such times, the best method to use with him was to say that a part of the experimental routine would be omitted. For instance, he was told that the alveolar air test would be omitted, but he was much distressed and insisted that it be made as usual. Again, the evening before, one of the assistants was directed not to insert the rectal thermometer unless the subject insisted upon it, but to say to L. that we did not wish to tire him with too many observations. The subject was much disturbed by this omission and insisted that the thermometer should be inserted. He was frequently inconsistent, at one time saying that there were too many experiments, too much going on, too many people about him, too many questions asked as to his feelings, and then almost immediately he would complain of being left too much alone to brood and to think of his family. He complained bitterly of his inability to get out of doors. He enjoyed very much his stay on the roof on April 21, but the weather had been raw and cold and, as he seemed very sensitive to cold, it did not seem wise to give him an outing.

April 25, 1912 (twelfth day of fast).—The records of the observer showed that L. slept very well the night before, as the subject rang the bell only once or twice throughout the whole night. He reported himself as being very comfortable. To lessen the number of observations so as not to overtire him, the tests of the blood-pressure and the alveolar air were omitted. In the afternoon L. went for a ride in a closed carriage; this he seemed to enjoy very much indeed. On this day, also, Dr. Southard examined him again, having a long talk with him. A letter which he received from his wife stated that his brother-in-law was very ill and later in the day he read in a Maltese paper of his brother-in-law's death. This depressed him very much.

April 26, 1912 (thirteenth day of fast).—L. slept fairly well in the calorimeter, ringing the bell about once an hour throughout the night. No odor was apparent when the chamber was opened. L. said that he was very comfortable; he seemed bright and in good spirits. In the afternoon he again went up on the roof, and subsequently a respiration experiment, with two periods,

was made with him while he was sitting in a chair. He was very drowsy and thought he could sleep throughout the whole night, as the previous night he had not slept as well as formerly. As he does not read in the evening, he found it somewhat tedious to sit idle until 8 o'clock, when he usually went into the calorimeter, and he asked to go into the apparatus an hour earlier. A respiration experiment was made early in the evening just before he went into the calorimeter, and this experiment was made a part of the experimental routine on subsequent days. He entered the bed calorimeter at 9 p. m.

April 27, 1912 (fourteenth day of fast).—The subject reported that he had had a very comfortable night; he rang the bell but twice during the whole time he was in the calorimeter chamber. About $10^h\ 45^m$ a. m., L. was taken in the elevator to the third floor of the laboratory, where he was shown about and several pieces of apparatus were explained to him. He then walked down-stairs to the second floor and when about a third of the way down, he commenced to move rapidly and finally actually ran down the stairs. In the office he looked at some photographs and dictated the following statement:

"To-day is the fourteenth day of my fast. I feel exceedingly well; I feel cheerful and hopeful of the grand success. I have slept several good hours during the night, and am enjoying with great enthusiasm all the experiences that are carried on me by the professor. I have to-day with Professor Benedict gone around the upper floors of the laboratory and I have admired all the great formalities that I have seen."

Subsequently he walked out into the hall and down-stairs to the calorimeter room, where he sat down in an arm chair and was the subject of a respiration experiment.

In the afternoon I spent about an hour with L. on the balcony. He was very cheerful and talked a great deal, gesticulating freely with his hands. He seemed to enjoy talking about the "beautiful island of Malta." He wore very much lighter clothing to-day, not using his heavy blanket wrapper at all. In fact, while walking about the laboratory, he carried his blanket wrapper over his arm, and although the office was a little cool, he did not put it on, but sat near the window.

One of the striking features of this fast is the fact that it has been so different from what he expected in many ways, a good illustration of the unreliability of personal impressions. For instance, he had expected to feel very chilly, but while he said he felt chilly the first two or three days, it is possible that this may have been due to his imagination, as subsequently he was not nearly so chilly and on this day asked that the temperature of the room should be lowered, which was done. He also said one of the first days that he was in the laboratory that he would have a large amount of phlegm as the fast progressed, but this had not been the case up to this date. While talking with Dr. Ash on this day, L. said that he had expected that he would become very hoarse during the fast, but thus far his voice had not changed, except to grow clearer. In the evening he was given a bath, his body being sponged with distilled water, after which he entered the calorimeter.

April 28, 1912 (fifteenth day of fast).—The experimental records show that the subject slept very well throughout the night and he himself reported a good night. In the afternoon he was taken out for a carriage drive, with the windows of the carriage open. He was well wrapped up, and said that he was perfectly comfortable and did not get too tired. He walked down to the basement and out to the carriage and on his return walked from the carriage up-stairs again into the calorimeter laboratory. He then sat down for several minutes and later a photograph was taken of him, with the blackboard showing

his body-weight curve as a background. He seemed unusually strong and active, walked with certain feet, and did not seem to be in any way exhausted or tired. He talked very excitedly during the whole of the drive; in fact, he talked continuously. He said that about 6 o'clock that morning he had had a normal seminal emission, which did not irritate him as did the one just prior to the fast. His observation was verified by Dr. Goodall's subsequent examination of the urine, a large number of spermatozoa being found.

April 29, 1912 (sixteenth day of fast).—When the calorimeter was opened in the morning, the usual absence of odor was recorded, and the subject reported himself as very comfortable and as having slept very well. Inasmuch as it was not L.'s custom to use a toothbrush—at least no toothbrush was found in his luggage and he had not brushed his teeth since his arrival in Boston—it seemed desirable to obtain some cultures of the micro-organisms of the mouth. These were secured by Dr. Kendall, of the Harvard Medical School, but the examination of them showed only adventitious organisms. L. was much interested in this test, especially as such a test had never been made in a previous fast. Early in the forenoon, he was very irritable and complained of the excessive amount of drinking water; he was especially disturbed because he had not heard from home. While Mr. Carpenter was making the respiration experiment in the afternoon, the subject did not seem quite so well as on other days.

April 30, 1912 (seventeenth day of fast).—When he came out of the chamber in the morning, L. reported that the night had been one of the best he had had since coming to the laboratory. The observer said that there was no odor and that the subject was very comfortable. Aside from the taking of a series of new photographs, the day was uneventful.

May 1, 1912 (eighteenth day of fast).—The observers' records show that the subject scarcely moved during the night, and that the bell rang only once or twice. There was no odor when the apparatus was opened. In the afternoon of this day, L. was taken for a drive.

May 2, 1912 (nineteenth day of fast).—L. reported a very comfortable night in the calorimeter; no odor was apparent when the apparatus was opened. At this stage of the fast, it had become very clear to the observers that L. had changed since the beginning. While he walked slowly and steadily and gave no special evidence of weakness, he was much less talkative, less inclined to offer advice, and more quiet and subdued. He was by no means so active a man as at the beginning of the fast. He complained that for several mornings past he had "felt his bones" during the night and was so uncomfortable that he waked up and turned over. It had become increasingly difficult to adjust the stethoscope so as to obtain a clear record of the pulse-rate. On this day so much difficulty was experienced that an assistant was detailed to watch the movement of an artery in the neck. His voice was somewhat weaker, though not husky, but it occasionally rose to its original tone. Furthermore, although he had maintained that about this period of the fast he would be intellectually better, he was in reality disinclined to read, write, or talk as much as at the beginning. This was well brought out by the fact that when he was told on this day that he ought to spend his time studying the principles of the apparatus and the technique rather than to trouble himself about the results, he stated that he did not want to spend so much time in this way and that he did not find himself very much interested in them, but that he would be better later on. This appears to contradict the statement that he would be more active intellectually as the fast progressed. He was measured by Dr. Anderson on this day, who remarked that, as he saw him only once a week, it was very obvious to him that he had changed very much since the beginning of the fast. His loss in flesh was of course much more apparent to Dr. Anderson than to

those of us who saw him daily. In the afternoon he was taken to the roof again, where he stayed for a little more than an hour. When he returned to the calorimeter laboratory, he sat down in a chair until the psychological tests began. He still had a great interest in the various tests and made the suggestion that the rectal thermometer be inserted before the evening respiration experiment, so as to get the temperature changes during this experiment.

May 3, 1912 (twentieth day of fast).—Although the subject reported that he did not sleep so well as he did the night before, he nevertheless had a fairly comfortable night. There was no odor apparent on opening the chamber. As the weather was exceptionally fine, L. was taken for a drive in the afternoon.

May 4, 1912 (twenty-first day of fast).—The subject reported this morning that he had had "several good hours of sleep." He was very comfortable, except that he had to change his position several times during the night. A number of unsuccessful attempts were made to take the pulse-rate with the string galvanometer, but the apparatus was broken. In the afternoon the subject was taken out driving. In the evening much time was spent in finding a suitable location for the stethoscope, and when the place was finally found it was so sharply localized that a movement of the stethoscope bell 1 cm. in any direction would prevent the taking of good records. It was then agreed upon that if during the night the pulse records were not obtainable, a signal to L. would be given, who would place the bell of the stethoscope as nearly as he could in the place decided on. Fortunately, on this and also on the following night the pulse-rate was secured with considerable regularity.

May 5, 1912 (twenty-second day of fast).—The experimental records showed that the subject remained very quiet throughout the night, ringing the bell only once or twice. In the afternoon of this day he was taken out for a carriage drive of two hours. He enjoyed this drive very much indeed, speaking enthusiastically about the beauty of Boston and its suburbs, and how it elevated him to see it. When he returned, he claimed that he was neither tired nor cold, although the air was cooler than when he went out the day before.

He had changed considerably during the preceding week, a fact which was noted by several persons who had not seen him during that period. He walked much more deliberately, but appeared to be perfectly sure of his footing. When he came down-stairs to take the psychological tests, he took the last three or four steps quite rapidly and stepped off briskly to greet Dr. Langfeld. On the other hand, at the end of the psychological test, he sat rather dejectedly in his chair. When Dr. Langfeld told him that the tests were over, however, he rose from the chair immediately, and returned to the balcony, but stopped half-way up the stairs to look at the string galvanometer with which we were working, and seemed as intellectually keen and bright as any one.

May 6, 1912 (twenty-third day of fast).—On coming out of the chamber, L. reported that he had a fairly comfortable night, sleeping very well. He complained, however, that as he had lost so much adipose tissue, he found it rather difficult for him to sleep on one side for any length of time, and he was obliged to turn from one side to the other frequently. The observers also found it extremely difficult to get the records of the pulse-rate. L. was much stimulated as a result of visitors in the forenoon. He exhibited a much sharper intellectual activity than had been apparent for several days, which might possibly prove his statement that he would become more intellectually keen as the fast progressed. Other than that we could see little evidence of the so-called intellectual activity that he had referred to frequently during the fast.

May 7, 1912 (twenty-fourth day of fast).—The subject was fairly quiet throughout the night, moving only occasionally. When the calorimeter was

opened, no odor was observed. Thus far in the fast, no acetone odors had been noted. In the forenoon a number of visitors came into the laboratory and several small photographs were taken of L. In the afternoon respiration experiment, when the subject sat writing, he was reported as being very obstinate and intractable. He seemed to have some difficulty in finding a position to suit him, and the nose-pieces had to be inserted a second time to make sure that they were well fitted. He also complained that the writing paper was too heavy, so that he would have to write on both sides of the paper to save postage. He appeared to be very difficult to please. At 5 o'clock on this day, L. reported that he was feeling very much depressed, owing to the weather, and that he spent the whole time thinking about home and was much worried.

May 8, 1912 (twenty-fifth day of fast).—The subject reported a very comfortable night, moving only once or twice during the night. In order to control the possible influence of small muscular movements on the temperature of the air in the chamber at the end of an experimental period, the height of the spirometer attached to the calorimeter was recorded on a smoked paper drum, a routine which proved very helpful on subsequent nights. On this morning L. was very sullen and disagreeable when spoken to, especially with Mr. Carpenter. He said that he had expected there would be a yellow pigmentation of the skin as in other fasts, but this did not appear. In the afternoon I asked him how much longer he wished to fast. He replied by asking how long I wanted him to fast. As I had previously told him on several occasions that I should like him to fast 30 days, it was obvious that he wished to be asked to stop fasting rather than to break the fast himself. I told him that we should probably wish him to fast for 30 or 31 days. The diet of the re-alimentation period was then discussed. He believed very strongly that the fast should be broken with acid fruit juices alone. The rectal thermometer remained in position throughout the day and the temperature records were secured for the greater part of the time.

May 9, 1912 (twenty-sixth day of fast).—The subject spent an unusually quiet night, ringing the bell only three times throughout the night. In the afternoon, during an active conversation which I had with him, in which general questions were discussed, he seemed to be very spirited, lively, and interested. His pulse-rate was 86 at this time. In the evening, when he came down-stairs to take the psychological test, he appeared to be quite unsteady on his feet and said that he was light-headed. He thought that his unsteadiness was due to the fact that he had lost so much weight that he put unusual strength on his foot, more than he needed to take his weight, and that this tended to unbalance him. Mr. Carpenter also noticed that when walking, L. was quite uncertain in his steps and thereafter we watched him more closely when he was on his feet. He said considerable on this day about the method of breaking the fast, emphasizing the fact that he wished to be able to say that the fast was broken by request and not by his desire. It was arranged to allow him to fast for 31 days, and then to begin taking food. He also expressed a preference for breaking his fast on a diet consisting of boiled rice and honey, with the juice of oranges and lemons and grape juice. Obviously such a diet should have many scientific points of interest, but it was questionable whether, after fasting so long, the stomach should be filled with the acids of oranges, lemons, and grapes. He was firmly convinced that this was the diet that should be used and could not be dissuaded from it. Subsequent experience proved the undesirability of this kind of a diet for breaking a long fast.

May 10, 1912 (twenty-seventh day of fast).—The subject reported that he did not sleep so well during the night as he had the night previous. He was not

uncomfortable in any way, but simply could not sleep. There was no noticeable odor. In a discussion with some physicians who visited him to-day, L. emphasized the fact that his tongue remained coated throughout the whole fast and that he had more or less of a bad taste in his mouth. His theory was that the waste products were not all eliminated from the body and that "they were trying to find their way out by the mouth." He thought that if he had defecated he would have had less discomfort. Although the subject went for a drive on the afternoon of this day, he complained that the weather had changed and that it was not pleasant. He also complained bitterly to Dr. Langfeld regarding Mr. Carpenter, saying that he would like to break every bone in his body. This would pronounce against fasting for amiability.

May 11, 1912 (twenty-eighth day of fast).—L. reported that it was late before he fell asleep and that he had not been able to sleep much or soundly during the night. In the early part of the evening, after he had been sealed into the calorimeter, he signaled that he was obliged to urinate and he had to be taken out. When he was sealed up again shortly after $10^h\ 30^m$ p. m., he thought he did not go to sleep until 12 o'clock. He moved several times during the night. During the afternoon of this day he spent some time on the roof, reading, and seemed to enjoy himself very much, appearing to be in good spirits all of the afternoon. But when he came down from the roof, he was extremely stubborn when taking his tests with Dr. Langfeld. For example, in a list of ten words which was read to him for memorizing, the eighth word was "wart." L. did not understand what it meant and asked to have it explained. Dr. Langfeld tried to keep him quiet until the list was read a second time, but he would not listen and insisted upon knowing what the word was. When Dr. Langfeld read the list to him a second time, he said that he had not heard the words, as he was thinking of what the word "wart" meant.

May 12, 1912 (twenty-ninth day of fast).—The subject said that he slept very well the previous night and in the morning seemed very bright. He busied himself much of the forenoon in writing a history of his life. (See p. 22.) A respiration experiment was made with him in the morning in which the subject breathed an atmosphere containing a large percentage of oxygen. In the afternoon I took him for a drive of 2 hours. During the drive he was bright and very talkative, telling a good deal about his family, his personal history, and his difficulty in getting an education. He became more quiet before he returned to the laboratory and in the psychological test he told Dr. Langfeld that the weather depressed him very much. He also told Dr. Langfeld that he was very sorry that I wanted him to break the fast and that he could easily fast for 10 days more; he did not like to break his fast until his tongue had become clear. On the other hand, he said that he would be out of the laboratory on May 23 and would be a free man again and "have free ice cream." It was evident that he would be difficult to control. There has been none of the pigmentation of the skin which he had expected and very little phlegm.

May 13, 1912 (thirtieth day of fast).—L. reported that he had slept well. He was in excellent spirits on this day and very lively and jolly. His movements were vigorous and he was unusually bright and active. All of his spare time was occupied in writing his autobiographical notes, which at this time covered 13 closely written pages. As usual he felt quite able to be photographed. At noon I asked him how he was and he replied that he felt very well indeed, saying: "We have seen the lighthouse and are now entering the harbor and will see land shortly."

In the afternoon I took him to the Boston City Hospital, where Dr. Francis H. Williams made an extensive series of X-ray photographs. L. was intensely

interested in this, and also thoroughly enjoyed the ride to and from the hospital. He was very much pleased with the whole day's program. He said that he was "now dropping anchor and therefore at the end of the voyage." His mental condition seemed to make a great difference in his whole make-up. On some days his faculties were very much keener than on others. For instance, during the test for visual acuity, he answered the position of the letter "E" with great strength of voice and with no hesitation whatever.

May 14, 1912 (thirty-first day of fast).—On this day, which was the last day of the fast, the program was very full, including an extensive series of photographs (see Plate 5) and the body measurements. The first word that L. spoke when the calorimeter was opened was in regard to having his photograph taken. In response to an invitation issued by the Nutrition Laboratory, a number of medical men from the vicinity of Boston came to see the subject between 2 and 3 o'clock in the afternoon. L. talked very rapidly and in a lively manner for nearly 40 minutes, setting forth his views in a more or less lucid manner to his audience. In the middle of his talk, I took his pulse-rate and found it to be 82. The subject was particularly desirous of having his photograph taken during the afternoon and wished to be photographed with each individual who had worked with him. In this afternoon talk with the physicians, L. made many conflicting statements. For instance, he said that he never used wine or alcohol in any form, while he had repeatedly told me that he frequently drank Malta wine and was not a teetotaler. He also reported that he was invariably a vegetarian, fruitarian, and nutarian, eating no meat; this was strikingly in contrast with the fact that he ate meat several times in the days just preceding the fast. During the visit of the physicians, he became very much excited and enthusiastic, evidently enjoying the opportunity of speaking to his audience. During the respiration experiment in the evening, he talked considerably about the end of the fast, saying that while he was not exactly tired, yet there was much emotion connected with his fast and he was thinking of the effect produced at home when the news reached them that he had completed the fast of 31 days successfully. Malta was awaiting the news and all of the people would be discussing his wonderful feat.

Figures D, E, and F in Plates 2 and 3 (pages 19 and 31) are from photographs secured on this last day of fasting. Figure E is of special interest, as it shows L. posing for 20 seconds while the exposure was being made. There is no evidence of unsteadiness.

RE-ALIMENTATION PERIOD.

May 15, 1912 (first day with food).—The bed calorimeter experiment was ended at $7^h\ 56^m$ a. m. When the apparatus was opened there was no odor apparent. The observer reported that the subject was comparatively quiet throughout the night, with but one movement between $11^h\ 44^m$ p. m. and $5^h\ 28^m$ a. m. L. complained, however, that he was kept awake by acid fumes and noise in the calorimeter room. Photographs were taken of the subject while he was upon the respiration apparatus, and also later in various positions. When he was weighed after the respiration experiment was over, it was found that he had lost 13.25 kilograms of his initial weight. He seemed much pleased that the fast was ended and spoke of the excitement there would be at his home when the cablegram was received announcing the successful completion of his fast.

The method of breaking the fast had been thoroughly discussed with the subject previously, but he insisted upon using lemons, oranges, grape juice, and honey. It was finally arranged that he should follow his own choice in the matter and, accordingly, lemons, oranges, boiled rice, and honey were

supplied him at his request. At $9^h\ 38^m$ a. m. he peeled and ate two lemons, using neither water nor sugar. In addition, three oranges, about 300 grams of honey, and approximately 1 liter of grape juice were taken in portions during the day. To study the flora of the colon, a rectal injection of sterile salt water was given him at $1^h\ 10^m$ p. m. About $4^h\ 30^m$ p. m. he complained of severe colic, but was somewhat relieved about $5^h\ 30^m$ p. m. by a copious movement of the bowels. Subsequently he again had colic, with a second movement of the bowels and vomiting. He appeared to be utterly wretched and weak, and to have entirely lost his courage. The contrast between his high spirits of the day before and his condition on this day was very striking.

No respiration experiments were attempted on this day after the ingestion of food, but a sample of the blood was taken, and records were made of the blood pressure and the alveolar air. Under the circumstances, it did not seem wise to have the subject sleep in the calorimeter. Arrangements were therefore made for him to sleep on a couch in the calorimeter laboratory, with a physician in constant attendance. While no records of the metabolism were obtained during the night, the pulse-rate was recorded by means of the stethoscope, the assistant sitting behind a screen out of sight of the patient.

May 16, 1912 (second day with food).—The subject passed a restless night, having another attack of colic about 2 a. m. and defecating. The pulse-rate through the night was somewhat higher than on previous nights. As he seemed weak and sick in the morning, Dr. Goodall, who came to see him early in the day, urged him to take some weak beef tea or clam broth, also toast, but he utterly refused to take anything of this nature, saying that such food would poison him. He furthermore said that as we were now through with him, we wished to poison him. He was as firmly convinced as ever that his method of breaking the fast was the correct one, but thought that he took food too soon and that he should have waited until his tongue had cleared, as he considered it dangerous to break the fast sooner. He told the physician in attendance during the night that a man might have to fast 100 days before the natural hunger would return. L. lay on the couch until about 10 a. m., when he went to the balcony and dressed. He continued his diet of fruit juices and honey throughout the day, but, at our urgent request, diluted the lemon juice with distilled water, taking first 77 c.c. of lemon juice, an equal amount of distilled water, and 11 grams of honey. Between $9^h\ 30^m$ a. m. and $7^h\ 30^m$ p. m., he drank at intervals a mixture containing the juice of 6 oranges, 367 c.c. of water, and 128 grams of honey, making a total volume of about 1,400 c.c. About $7^h\ 30^m$ p. m., he took the juice of another orange, saying that he was hungry but felt very well. During the day Dr. Goodall made the usual physical examination; the blood pressure and the alveolar air were also observed. The subject entered the bed calorimeter at $8^h\ 14^m$ p. m. for the usual night experiment.

May 17, 1912 (third day with food).—At 10 p. m. the subject telephoned and urinated, but after that time the experimental records show that he was very quiet. When he left the apparatus in the morning, he said that he had had a very comfortable night, sleeping better than he had for years. He thought he must have had at least 10 hours of dreamless sleep. He appeared to be in good spirits. The usual respiration experiment was made with him this morning. Throughout the day, he continued taking at intervals a mixture of orange juice and honey, diluted with water; he was also supplied with raisins and dates. The usual physical examination was made by Dr. Goodall; also tests of the blood pressure, the alveolar air, and for acetone in the breath. A sample of the blood was taken by Dr. Ash. In the afternoon he went up on the roof for a time, but was ill-humored, very difficult to please, and full of

complaints. The day before I had taken exception to his statements that we were to blame for his illness on taking food and had shown him that he had chosen his own diet and had refused to be guided by the advice of the physicians. He was greatly offended at this, and was disagreeable to every one in consequence all of this day. When Dr. Langfeld came at about 5 o'clock for the psychological tests, he burst forth in a long tirade, complaining of nearly every member of the staff, and of his treatment at the laboratory. He claimed that throughout the night, while in the calorimeter, he was left in charge of "boys," who paid no attention to him, and that he might die there without any one knowing of it. He had said nothing about this to me, but asked Dr. Langfeld to tell me.

In the evening L. again had colic, with diarrhea and vomiting. He entered the calorimeter for the regular experiment at $8^h\ 35^m$ p. m., but only on the condition that Mr. Emmes or Mr. Carpenter should stay in the calorimeter room all of the night. Accordingly Mr. Carpenter slept on a couch in the balcony, so as to be near if needed during the night, the usual experienced observers being on duty. At 10 p. m. it was reported to me that the subject had a pulse-rate of 104 and body-temperature (rectal) of approximately 38° C. I went to the calorimeter laboratory and remained there for a time, thinking that he might be suffering from colic and would have to be taken out. About $10^h\ 30^m$ p. m. he telephoned that he wished to defecate. He was accordingly taken out of the calorimeter. After defecating, he returned to the apparatus and the experiment began at $11^h\ 57^m$ p. m.

May 18, 1912 (fourth day with food).—The subject had a restless night, being evidently suspicious, unhappy, and discontented. He called for Mr. Carpenter about 3 a. m. and asked if something had not fallen upon the calorimeter, as he had felt a jar. He was assured that nothing of the kind had happened, both of the observers having been sitting quietly at their respective posts when he called. He was taken out of the apparatus at $5^h\ 45^m$ a. m. and said that he had not slept all night. His pulse-rate and respiration-rate were high; the body-temperature was also slightly elevated. He seemed apprehensive and was apparently mentally unbalanced, talking in an irrational way with Dr. Goodall. The usual respiration experiment was made with him on this morning and he was weighed, but no other observations were taken.

After the respiration experiment, he complained of exhaustion, but finally returned to the balcony and began to eat; his attitude towards nearly every member of the staff was suspicious and antagonistic. He insisted that the British consul should be asked to come to the laboratory to confer with him, which was done. It was finally decided that considering his condition and general attitude, he would more quickly recover his balance if cared for at a hospital. Arrangements were made with the Massachusetts General Hospital to defray the expense of his care and he was taken there in a carriage by one of the members of the staff, and placed in a private room. On May 19 he was seen by Dr. Goodall, who found him very contrite. He asked Dr. Goodall to find me at once and to apologize for his behavior the day before.

By permission, a copy of the hospital records is appended herewith, giving the history of his stay in the Massachusetts General Hospital.

"*May 18.*—Patient states that he completed a 30-day fast under observation at the Carnegie Nutrition Laboratory three days ago, and that he was sent here to-day through a misunderstanding and that he should not be in a hospital. History and physical examination not attempted by order of Dr. Langnecker, superintendent on duty.

"*May 19.*—Seems contented, cheerful, and comfortable. Eats with good appetite and relish. Says the bed is not as comfortable as the calorimeter.

"*May 20.*—Patient was very angry on coming into the hospital, first, because he was in a public institution, whereas he had expected to go into a 'convalescent home for wealthy people.' Second, because the fact of his going to a hospital after his fast would detract from the renown and interest of his feat.

"Yesterday he appeared very happy. He seemed to realize and accept that there were certain disadvantages here. He was asked what diet he wanted and requested straight house diet, and this was given him in accordance with the ideas of Dr. Benedict. He ate this with relish. He appeared a little weak, but able to be about. He spent the day in writing and in sorting out various articles and pictures, of which he had a half of a valise full.

"Last night he was nauseated and vomited several times, but was not ill enough to be reported. This morning he was again very angry. He complained that oatmeal was very bad for a man recovering from starvation. He repeated his complaints of Saturday (May 18) and said that he was being held by conspiracy and wanted to summon or go to the British consul. He was therefore discharged at his own request.

"While at the front door waiting to have his bill arranged and his valuables procured, he complained loudly that his possessions were being withheld from him. While waiting for a carriage to be summoned, he called out loudly many times that he would get out of here if he had to crawl on his hands and knees.

"While in the wards he was shown every attention by the nurses, and especially all food and drink brought to him as desired.

"Discharged to own M. D. (Not treated)."

Subsequent to his leaving the Massachusetts General Hospital, L. was seen by Drs. Langfeld and Goodall and a second set of X-ray photographs was taken by Dr. Williams. Such data as were secured are included in the individual reports.

PHYSICAL CONDITION OF THE SUBJECT DURING THE FAST.

By Harry W. Goodall,
Department of Physiological Chemistry, Harvard Medical School.

A complete physical examination of the subject was made 60 hours before the beginning of the fast, on the first day of the fast, and every alternate day thereafter. So far as possible, the same conditions as to time of day, posture, methods, etc., were observed at each examination. The percussion outline of the various organs was marked with pencil and these lines were not disturbed until variations in the size of the organs made it necessary. Owing to the thinness of the subcutaneous tissue the percussion note could be sharply defined and the favorable mental attitude of the subject permitted complete muscular relaxation.

Family history.—Father 68 years of age, mother 64 years, both living and well. Two sisters, one 27 years of age, the other 19 years, both living and well. One sister died in infancy of malaria. One brother died in childhood of croup. Twin brother died in infancy, cause unknown.

Past history.—Was a delicate child, the most pronounced characteristic being a sensitive nervous organization. Does not remember about diseases of childhood. In his twentieth year (20 years ago), while in the university, he had a severe nervous breakdown and had to give up his studies. Has suffered from neurasthenia since. Has been under the care of several physicians at different periods without receiving any benefit. Being discouraged with these experiences, he became interested in certain popular articles advocating fasting as a cure for diseases, including neurasthenia, and in April 1910 he underwent his first fast. So great was the improvement in his nervous condition following this fast that he has since devoted much of his attention to the study of fasting. Previous to the present experiment he has undergone the following fasts:

April 1910. Fasted 8 days, taking nothing but water; not under observation.

March 1911. Fasted 40 days, taking nothing but water; under partial observation.

August 1911. Fasted 12 days, taking nothing but water; under partial observation.

November 1911. Fasted 5 days, complete fast; not under observation.

These experiences have convinced him that, in health, food not only makes the individual susceptible to diseases and causes disease, but also interferes with the proper exercise of the mental faculties. He states that during the fasting period the mind is clear and alert and that there is a strong desire for study. It is now the practice of his wife, his two children, and himself to abstain entirely from food during any illness, and he is convinced that the severity of any disease is reduced, the subjective symptoms made less disagreeable, and the course of the disease shortened if such a course is pursued.

His personal experiences and his study have been so convincing that he was desirous of undergoing a scientific experiment, under the most perfect conditions, for the benefit of humanity. Having learned that the most perfect equipment in the world was at the Nutrition Laboratory, he applied for the privilege of undergoing this experiment there. He expressed his pleasure at the cordial manner in which he had been received at the laboratory, and stated that he was very happy in the thought that he was about to undertake the fast, not alone on account of the scientific value of the experiment, but also because of the improvement which he anticipated in his own well-being. He expressed his pleasure in going into minute details as to his subjective feelings.

RESULTS OF PHYSICAL EXAMINATION.

April 11, 1912 (60 hours before beginning the fast):

A well-developed, well-proportioned, and fairly well-nourished man. Height, 170.7 cm.; weight, 60.1 kilograms; age, 40 years. Stands erect. Walks with body erect, with no abnormalities in the gait. Hair of head and beard dark. Skin has a muddy yellowish tinge, but is soft and moist. Slight conjunctivitis of both eyes. Very moderate amount of subcutaneous fat. Muscles of moderate size but rather soft. Has a small infected papule on left alæ nasæ. No pulsations noted in the neck, chest, or abdomen. No visible abnormalities.

Mouth: Mucous membrane of the lips and cheeks of good color and moist. Tongue moist with a slight coating, especially on the central and posterior portions. Teeth in fair condition. There is a slight deposit of discolored tartar at the base of the teeth and two teeth have temporary soft fillings. No particular odor to the breath. No enlargement of the tonsils. Pharynx is reddened, the blood vessels dilated, and there are a few blebs on the posterior pharyngeal wall with a little mucus adhering.

Glands: Cervical, axillary, and epitrochlea glands not palpable. A few small glands in both groins.

Reflexes: Pupils equal and react normally to light and distance. Abdominal, cremasteric, patella, Achilles, and plantar reflexes normal.

Chest: Symmetrical, well formed, some sinking in of the supra- and infraclavicular spaces. Good expansion with inspiration. No bulging of the præcordia, and apex beat of heart is not visible or palpable.

Lungs: Percussion of the right lung shows normal resonance to the upper border of the fifth rib in the nipple line, to the lower border of the fifth rib in the axillary line, and to the eleventh rib in the back. On the left normal resonance to the eighth rib in the mid-axillary line and to the eleventh interspace in the back. Vocal fremitus is slightly increased and expiration slightly prolonged at the right apex, extending to the second rib in front and the spine of the scapula behind. There were no râles and the lungs were otherwise negative.

Heart: The area of superficial cardiac dullness (light percussion) was measured from a perpendicular line through the mid-sternum and a horizontal line drawn at the level of the nipples. The upper border of cardiac dullness was at the third interspace. The left border of cardiac dullness was 9.5 cm. from the mid-sternum, 1.2 cm. inside the nipple. The right border of cardiac dullness was 1.2 cm. from

April 11, 1912—Continued.

the mid-sternum. The total width of cardiac dullness was 10.7 cm. The cardiac sounds were somewhat distant, but of good quality and regular rhythm. There were no murmurs to be heard. The aortic and pulmonic second sounds were of equal intensity.

Pulse: The pulses were equal, regular at the rate of 82 per minute. Rhythm regular, volume fair. No sclerosis of the vessels noted.

Abdomen: The abdomen was symmetrical, rather prominent when standing, but flat when reclining. It was soft, tympanitic, but with no distension. There was no tenderness on palpation. Nothing abnormal was felt.

Liver: The upper border of liver dullness was at the lower border of the fifth rib in the nipple line. The lower border of liver dullness was 1 cm. below the costal margin. Total width of dullness 11.5 cm. The edge of the liver was indistinctly palpable, soft, and without irregularities.

Stomach: The measurements of the stomach were determined as accurately as possible by means of auscultatory percussion. The lines of measurement were the median line of the body and a horizontal line through a point half-way between the tip of the ensiform and the umbilicus. Tympany in the median line extended from the tip of the ensiform to a point 3.5 cm. above the umbilicus, a total distance of 11 cm. The left border of tympany extended to a point 16 cm. from the median line. Faint rhythmic sounds were to be heard with the stethoscope. There was no splashing with palpation.

Spleen: The upper border of splenic dullness was at the eighth rib. The area of splenic dullness was vaguely determined as 7×5 cm. The spleen was not felt.

Kidneys: Neither kidney was palpable.

Genital organs: Aside from a long prepuce and a slight left variococele, the penis and testicles were normal.

April 14, 1912 (first day of fast):

Abdomen: Not as prominent. Flat to percussion everywhere except over the area of stomach tympany.

Stomach: No rhythmic sounds heard.

No change noted in general appearance, mouth, glands, reflexes, chest, lungs, heart, pulse, liver, spleen, kidneys, or genital organs.

April 16, 1912 (third day of fast):

Mouth: No change noted, with the exception of a pronounced odor to the breath.

Reflexes: No change noted except patella reflex not as active.

Liver: Lower border of liver dullness at costal margin. Total width of dullness 10.5 cm. Edge not felt. (First change noted.)

Stomach: Tympany in the median line extends from a point 3 cm. above the tip of the ensiform to 7 cm. above the umbilicus. Total width 10.5 cm. Left border of tympany 18 cm. from the median line. Active peristalsis with pronounced rhythmic sounds.

No change noted in general appearance, glands, chest, lungs, heart, pulse, abdomen, spleen, kidneys, or genital organs.

April 18, 1912 (fifth day of fast):

Mouth: No change noted. Odor to breath still pronounced and tongue more heavily coated.

Reflexes: Patella reflexes only obtained with reenforcement.

April 18, 1912—Continued.

Abdomen: Not as prominent while standing, retracted while reclining. Dull to percussion, except over the area of stomach tympany. Marked visible pulsation of the aorta.

Liver: No change from note of third fasting day.

Stomach: Tympany in the median line from a point 3.5 cm. above the tip of ensiform to 7.5 cm. above umbilicus. Total width, 10.5 cm. Left border of tympany 16 cm. from median line. Rhythmic sounds were audible but not marked.

No change noted in general appearance, glands, chest, lungs, heart, pulse, spleen, kidneys, or genital organs.

April 20, 1912 (seventh day of fast):

General appearance: No change noted, except that the features are slightly drawn and subject moves about a little more slowly.

Mouth: No change from note of fifth fasting day.

Reflexes: No change in pupillary and plantar reflexes. Patella reflexes obtained with difficulty. Achilles reflex very slight.

Heart: Left border of cardiac dullness 8.5 cm. and right border 1 cm. from mid-sternum. Total width, 9.5 cm. (first change noted). No change in character of sounds.

Abdomen: No change from note of fifth fasting day.

Liver: No change from note of third fasting day.

Stomach: Tympany from a point 3 cm. above the tip of the ensiform to 8 cm. above the umbilicus. Total width 9.5 cm. Left border 14 cm. from median line. Rhythmic sounds heard.

No change noted in glands, chest, lungs, pulse, spleen, kidneys, or genital organs.

April 22, 1912 (ninth day of fast):

General appearance: Conjunctivitis not quite so marked. Infected papule on the nose has disappeared. Otherwise no particular change.

Mouth: Mucous membrane of tongue and mouth dry. Tongue slightly less coated. Odor to breath not so pronounced.

Reflexes: Patella and abdominal reflexes absent. Achilles reflex obtained only with difficulty. Cremasteric and plantar reflexes normal.

Heart: Left border of cardiac dullness 8 cm., right border 1 cm. from mid-sternum. Total width 9 cm. (second change in size of heart noted). No change in character of sounds.

Abdomen: No change from note of fifth day.

Liver: No change from note of third day.

Stomach: Tympany from a point 4 cm. above tip of ensiform to 8 cm. above the umbilicus. Total width, 10.5 cm. Left border tympany 14 cm. from median line.

No change noted in glands, chest, lungs, pulse, spleen, kidneys, or genital organs.

April 24, 1912 (eleventh day of fast):

General appearance: Features somewhat drawn. Muscles not quite so firm. Skin more elastic. Seborrhea sicca of entire scalp. Walks without evidence of weakness. No unsteadiness when standing with eyes closed.

Mouth: Mucous membrane of mouth and tongue dry. Lips dry and desquamating. Odor to breath less marked.

Reflexes: No change from note of ninth day of fast, except Achilles reflex absent.

Chest: Some sinking in of supra- and infra-clavicular spaces.

April 24, 1912—Continued.

Heart: No change noted in measurements of heart from ninth day of fast. Faint systolic souffle heard all over the præcordia, loudest at the apex. Not transmitted, and not related to the respiratory murmur. Intensity not influenced by posture. Heart sounds not so distinct.

Pulse: Volume of pulse not so good.

Abdomen: No change from note of fifth day of fast.

Liver: No change from note of third day of fast.

Stomach: No change from note of ninth day of fast. Rhythmic sounds heard.

No change noted in glands, lungs, spleen, kidneys, or genital organs.

April 26, 1912 (thirteenth day of fast):

General appearance: Features not so drawn. Conjunctivitis somewhat improved. Otherwise no change from note of eleventh fasting day.

Mouth: No change from note of eleventh fasting day.

Reflexes: No change from note of eleventh fasting day.

Chest: No change from note of eleventh fasting day.

Heart: No change from note of eleventh fasting day.

Pulse: No change from note of eleventh fasting day.

Abdomen: Markedly retracted when reclining.

Liver: No change from note of third fasting day.

Stomach: Tympany from a point 3 cm. above tip of ensiform to 8 cm. above the umbilicus. Total width 10.5 cm. Left border of tympany 12.5 cm. from median line. Rhythmic sounds heard.

Kidneys: Pole of right kidney just palpable. (First change noted.)

No change noted in glands, lungs, spleen, or genital organs.

April 28, 1912 (fifteenth day of fast):

General appearance: Odor to breath less pronounced. Stands erect. Has normal gait but moves about more deliberately. Seborrhea sicca much improved.

Mouth: Mucous membrane of mouth and lips moist. No desquamation of lips. Tongue slightly less coated.

Reflexes: No change from note of eleventh fasting day.

Chest: No change from note of eleventh fasting day.

Heart: No change in measurements of heart from note of ninth fasting day. The systolic souffle which appeared on the eleventh fasting day is no longer heard. Intensity of heart sounds not increased.

Pulse: No change noted from note of eleventh fasting day.

Abdomen: Retracted. Dull to percussion everywhere except over the area of stomach tympany. No tenderness on palpation except slight tenderness over the pulsating aorta. The large intestines appear to be about the size of a thumb and can be rolled under the finger extending from the cæcum up to the right hypochondrium and from the left hypochondrium down to the brim of the pelvis. There is no gurgling with pressure.

Liver: The upper border of liver dullness is 1 cm. lower than at the beginning of the fast. Total width 9.5 cm. (second change in size).

Stomach: Tympany from a point 8 cm. above the umbilicus. Total width 9.5 cm. Left border of tympany 13 cm. from the median line. Rhythmic sounds heard.

Kidneys: No change from note of thirteenth fasting day.

No change noted in glands, lungs, spleen, or genital organs.

April 30, 1912 (seventeenth day of fast):
General appearance: Features not so drawn, otherwise no change from note of fifteenth fasting day.
Mouth: Desquamation of lips entirely disappeared, otherwise no changes from note of fifteenth fasting day.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Heart: Left border of cardiac dullness 7.5 cm., right 0.5 cm. from median line. Total width 8 cm. (third change in the size of heart noted.) No further change in quality of heart sounds.
Pulse: No change from the note of the eleventh fasting day.
Abdomen: No change from the note of the fifteenth fasting day.
Liver: No change from the note of the fifteenth fasting day.
Stomach: No change from the note of the fifteenth fasting day.
Kidneys: No change from the note of the thirteenth fasting day.
No change noted in glands, lungs, spleen, or genital organs.

May 2, 1912 (nineteenth day of fast):
General appearance: No change from note of seventeenth fasting day.
Mouth: No change from note of seventeenth fasting day.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Heart: Left border of cardiac dullness 7 cm. from the median line, right border at median line. Total width, 7 cm. (fourth change in measurements of heart noted). No change in quality of sounds from the note of the fifteenth fasting day.
Pulse: No change from note of eleventh fasting day.
Abdomen: No change from note of fifteenth fasting day.
Liver: No change from note of the fifteenth fasting day.
Stomach: Tympany from a point 1.5 cm. above tip of the ensiform to 8.5 cm. above the umbilicus. Total width, 8.5 cm. Left border of tympany 11 cm. from median line. No rhythmic sounds heard.
Kidneys: No change from note of the thirteenth fasting day.
No change noted in glands, lungs, spleen, or genital organs.

May 4, 1912 (twenty-first fasting day):
General appearance: The soft parts of the extremities not so firm and not so large. Otherwise no change from the note of the seventeenth fasting day.
Mouth: No change from the note of the seventeenth fasting day.
Reflexes: No change from the note of the eleventh fasting day.
Chest: No change from the note of the eleventh fasting day.
Heart: No change from the note of the nineteenth fasting day.
Pulse: No change from note of the eleventh fasting day.
Abdomen: No change from the note of the fifteenth fasting day.
Liver: Upper border of liver dullness at sixth rib, lower border at costal margin. Total width 9.0 cm. (third change noted in size of liver).
Stomach: Area of tympany the same as noted on the nineteenth fasting day. Rhythmic sounds heard.
Kidneys: Right kidney palpable, pole of left kidney (for first time) just felt with deep inspiration.
No change noted in glands, lungs, spleen, or genital organs.

May 6, 1912 (twenty-third day of fast):
General appearance: No change from note of the twenty-first fasting day.
Mouth: Mucous membrane moist. Very slight coating on tongue. Very little odor to breath.

May 6, 1912—Continued.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Heart: Measurements of cardiac dullness the same as noted on the nineteenth fasting day. The cardiac sounds are rather more distant. The aortic second sound is a little louder than the pulmonic sound.
Pulse: No change from note of eleventh fasting day.
Abdomen: Very slight gurgling (gas and liquid) with palpation of the right hypochondrium.
Liver: No change from note of twenty-first fasting day.
Stomach: No change from note of twenty-first day, except that rhythmic sounds are heard.
Kidneys: No change from note of twenty-first fasting day.
No change noted in glands, lungs, spleen, or genital organs.

May 8, 1912 (twenty-fifth day of fast):
General appearance: No change from note of twenty-first fasting day.
Mouth: Mucous membrane moist. Good color. Tongue nearly clean. Very little odor to breath.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Heart: Left border of cardiac dullness 6.8 cm. from mid-sternum. Right border 0.3 cm. to left of mid-sternal line. Total width 6.5 cm. (fifth change noted in measurements of heart). First sounds of the heart not distinct.
Pulse: No change from note of eleventh fasting day.
Abdomen: Retracted. Dull to percussion except over area of stomach tympany. No gurgling on palpation and no tenderness except over the pulsating aorta.
Liver: Lower border of liver dullness unchanged. Total width of dullness 8.6 cm. (fourth change noted in size of liver).
Stomach: No change in area of stomach tympany from note of twenty-first fasting day. No rhythmic sounds heard.
Kidneys: No change from note of twenty-first fasting day.
No change noted in glands, lungs, spleen, or genital organs.

May 10, 1912 (twenty-seventh day of fast):
General appearance: No special change from note of twenty-first fasting day.
Mouth: Tongue nearly clean. Odor of breath not specially marked.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Heart: No change from note of twenty-fifth fasting day.
Pulse: No change from note of eleventh fasting day.
Abdomen: No change from note of twenty-fifth fasting day.
Liver: No change from note of twenty-fifth fasting day.
Stomach: No change from note of twenty-first fasting day.
Kidneys: No change from note of twenty-first fasting day.
No change noted in glands, lungs, spleen, or genital organs.

May 12, 1912 (twenty-ninth fasting day):
General appearance: No change from note of twenty-first fasting day.
Mouth: No change from note of twenty-seventh fasting day.
Reflexes: No change from note of eleventh fasting day.
Chest: No change from note of eleventh fasting day.
Lungs: The percussion note at both apices and just below the clavicle is slightly higher pitched. No change noted in the respiratory murmur.

May 12, 1912—Continued.

Heart: No change from note of twenty-fifth fasting day.

Pulse: No change from note of eleventh fasting day.

Abdomen: Aside from a slight gurgling of gas and liquid in the right hypochondrium with palpation no change noted from twenty-fifth fasting day.

Liver: Total width of liver dullness 7.4 cm. (fifth change noted in size of liver).

Stomach: No change from note of twenty-first fasting day. Rhythmic sounds heard.

Kidneys: No change from note of twenty-first fasting day.

No change noted in glands, spleen, or genital organs.

May 14, 1912 (thirty-first day of fast):

General appearance: The features have a drawn appearance. Subject stands erect. Walks with body erect and shows no abnormalities in gait but moves about slowly as if fatigued. The skin has a muddy yellowish appearance but is soft and moist. The skin is relaxed and is easily picked up, as if there were but little subcutaneous fat. The muscles are rather small and not firm. There is a slight conjunctivitis of both eyes. No abnormal pulsation noted in the neck or chest, but the pulsation of the abdominal aorta is marked, especially when reclining.

Mouth: Mucous membrane of the lips and cheeks of good color and moist. Tongue moist, with a very slight coating on the posterior part. Teeth show a slight deposit of discolored tartar at the base. The breath has a very slight odor. No enlargement of the tonsils. The pharynx shows some injection of the blood vessels and a few blebs on the posterior pharyngeal wall. There is a little mucus on the posterior naso-pharynx.

Glands: Cervical, axillary and epitrochlea glands not palpable. A few small glands in both groins.

Reflexes: Pupillary, cremasteric, and plantar reflexes normal. Abdominal, patella and Achilles reflex not obtained. No ankle clonus. No Rhomberg.

Chest: Symmetrical. Ribs prominent. Marked sinking in of the supra- and infra-clavicular spaces. Good expansion with inspiration.

Lungs: Percussion of the right lung shows normal resonance to the lower border of the sixth rib in the axillary line, to the eleventh rib in the mid-axillary line and the eleventh rib in the back. On the left normal resonance to the eighth rib in the mid-axillary line and to the eleventh interspace in the back. The percussion note is high pitched at both apices. Vocal fremitus is slightly increased at both apices, more especially on the right. The respiratory murmur is normal throughout.

Heart: The upper border of cardiac dullness is at the fourth rib; the left border of cardiac dullness 6.8 cm. from the mid-sternum; the right border 0.3 cm. to the left of the mid-sternal line. Total width, 6.5 cm. The cardiac sounds are distant; the first sound of the heart is not clear. The aortic second sound is somewhat sharper than the pulmonic second.

Pulse: The pulses are equal and regular, but small volume. No sclerosis of vessels noted.

May 14, 1912—Continued.

Abdomen: Symmetrical. Flat when standing. Much retracted when reclining. Marked visible pulsation of the abdominal aorta. The abdomen is everywhere flat to percussion except over the area of stomach tympany. There is no tenderness except over the abdominal aorta. Intestines about the size of a thumb; can be rolled under the finger extending from the cæcum to the right hypochondrium and from the left hypochondrium down to the brim of the pelvis. There is slight gurgling with pressure in the right hypochondrium.

Liver: The upper border of liver dullness is from the lower border of the sixth rib to the costal margin. Total width of liver dullness 6 cm. Edge not felt.

Stomach: Tympany from a point 2 cm. above tip of the ensiform to a point 8 cm. above the umbilicus. Total width 9.5 cm. Left border of tympany 13 cm. from median line. Rhythmic sounds heard.

Spleen: The upper border of splenic dullness is at the eighth rib. Area of splenic dullness vaguely determined as 6×5 cm. The spleen was not felt.

Kidneys: Right kidney readily palpated. The pole of left kidney is felt.

Genital organs: Aside from a long prepuce and a slight variococele on the left, the penis and testicles are normal.

May 15, 1912 (two hours after breaking fast):

General appearance: Features slightly drawn. Walks erect but deliberately, as if fatigued. No unsteadiness in gait. The tongue is clean and there is no odor to the breath. Otherwise no change in the physical examination from notes of the thirty-first and last day of fast.

May 16, 1912 (24 hours after breaking fast):

General appearance: Features quite drawn. Walks hesitatingly and a little unsteadily. Marked lassitude. Voice weak and faltering.

Mouth: Mucous membrane of lips and tongue dry. Tongue slightly coated posteriorly.

Abdomen: When subject is standing, abdomen is symmetrical and slightly more prominent than on last day of fast. When reclining, the abdomen is not so retracted. The right half of the abdomen is somewhat more prominent than the left. The right half of the abdomen is tympanitic; the left half flat to percussion. Palpation of the right half elicits some rumbling of gas and liquid and causes slight pain. Rhythmic sounds are heard on the right half.

Liver: Upper border of dullness at upper border of sixth rib, lower border at the costal margin. Total width, 7.5 cm. (1.5 cm. wider than on last day of fast). Edge not palpable.

Stomach: Tympany from a point 2.5 cm. above ensiform to a point 8 cm. above the umbilicus. Total width, 10 cm. Left border of tympany 17 cm. from median line. Rhythmic sounds heard. Otherwise the physical examination is the same as on the last fasting day.

May 18, 1912 (3 days after breaking fast):

General appearance: Features appear thin but not drawn. Walks slowly but with no unsteadiness. Voice more natural.

Mouth: Tongue is clean.

Heart: The left border of cardiac dullness is 7 cm. from the mid-sternal line, the right border at the mid-sternal line. Total width 7 cm. (0.5 cm. larger than on last fasting day.) Both sounds of heart distant but clear and distinct.

May 18, 1912—Continued.

Pulse: Good volume to pulse.

Abdomen: Slightly more prominent when standing. Abdomen full when reclining. Symmetrical. Tympanitic all over, with no difference between the two sides.

Liver: Upper border of liver dullness at fifth rib, lower border at costal margin. Total width, 11.5 cm. (the same as at the beginning of the fast). Edge not felt.

Stomach: Tympany from a point 4.5 cm. above the tip of the ensiform to a point 5.5 cm. above the umbilicus. Total width, 13.5 cm. The left border of tympany extends to a point 16 cm. from the median line. Rhythmic sounds heard. Otherwise no change from the last fasting day noted in the physical examination.

May 19, 1912 (4 days after breaking fast):

General appearance: Features drawn. Conjunctivæ injected (from weeping). Forehead bathed in cold perspiration. Marked tremor to hands. Gait unsteady. Walks as if quite weak physically. (General condition that of hysteria.)

Tongue: The tongue is clean.

Heart: Left border of cardiac dullness 7 cm. from median line. Right border 0.5 cm. to right of mid-sternum. Total width, 7.5 cm. Sounds clear and more distinct. Aortic and pulmonic second sounds of equal intensity.

Stomach: Tympany from a point 4.5 cm. above the tip of the ensiform to 2.5 cm. above the umbilicus. Total width, 15.5 cm. Left border of tympany 16 cm. from the median line. Rhythmic sounds heard. Otherwise no change from the last fasting day noted in the physical examination.

October 19, 1912 (5 months after breaking fast):

General appearance: General aspect not that of a well-nourished man. Weight 126 lbs., 15 ounces (57.6 kilograms) (nude). Stands erect. Gait normal. Skin has a muddy yellowish tinge, but is soft and moist. Slight conjunctivitis of both eyes. Small amount of subcutaneous fat. Muscles moderate in size and rather soft. No pulsation noted in neck, chest, or abdomen.

Mouth: Mucous membrane of lips and cheeks moist and of good color. The tongue has a slight coat, especially on the posterior portion. Deposit of discolored tartar on the teeth. Slight odor to breath. Pharynx is reddened, the blood vessels injected, and some mucus adherent.

Glands: Cervical, axillary and epitrochlea glands are not palpable. A few small glands in both groins.

Reflexes: Pupils equal and react normally to light and distance. Abdominal, cremasteric, patella, Achilles, and plantar reflexes normal.

Chest: Symmetrical, well formed. Some sinking in of the supra- and infra-clavicular spaces. Good expansion with inspiration. No bulging of the præcordia and apex beat of the heart is not visible or palpable.

Lungs: Percussion of the right lung shows normal resonance to the upper border of the fifth rib in the nipple line, to the lower border of the fifth rib in the axillary line, and to the eleventh rib in the back. On the left normal resonance to the eighth rib in the mid-axillary line and to the eleventh interspace in the back. Vocal fremitus is slightly increased and expiration slightly prolonged at the right apex, ex-

October 19, 1912—Continued.

tending to the second rib in front and the spine of the scapula behind. There were no râles and the lungs were otherwise negative.

Heart: Left border of cardiac dullness 9 cm. from mid-sternum. Right border 2 cm. to right of mid-sternum. Total width, 11 cm. Sounds clear. No murmurs. Aortic and pulmonic second sounds of equal intensity.

Pulse: The pulses were equal, regular at rate of 82 per minute. Rhythm regular, volume fair. No sclerosis of the vessels noted. Systolic blood pressure, 120 mm. Hg., diastolic, 85 mm. (Riva-Rocci instrument, sitting position.)

Abdomen: The abdomen is symmetrical, rather prominent when standing but flat when reclining. It is soft, tympanitic, but no distension. There is no tenderness on palpation. Nothing abnormal felt.

Liver: The upper border of liver dullness at the upper border of the sixth rib. Dullness extends to 2 cm. below costal margin. Total width of dullness 11 cm. Edge indistinctly palpable, and with no irregularities.

Stomach: Tympany in the median line extended from the tip of the ensiform to a point 3.5 cm. above the umbilicus, a total distance of 11 cm. The left border of tympany extended to a point 16 cm. from the median line. Faint rhythmic sounds are to be heard with the stethoscope. There is no splashing with palpation.

Spleen: The upper border of splenic dullness is the eighth rib. Area of splenic dullness vaguely determined as 7×5 cm. Spleen not felt.

Kidneys: Neither kidney palpable.

Genital organs: Aside from a long prepuce and a slight left variococele, the penis and testicles are normal.

SUMMARY AS TO PHYSICAL CONDITION.

General appearance: The general appearance of the subject remained good throughout the period of observation. A gradual loss of body tissue was evident, but the changes were not marked from day to day. The most pronounced change was in the abdomen, which became flat as soon as he ceased to take food and was distinctly retracted after the fifth fasting day. This for the most part appeared to be due to the prompt disappearance of gas in the intestines. The actual loss in body tissue appeared to be quite evenly distributed over the body, but was most noticeable in the tissue of the back of the neck, in the sinking in of the supra- and infra-clavicular spaces, and in the prominence of the ribs.

The muscles of the extremities, which were but moderately firm at the beginning of the fast, appeared to have softened to a slight degree. The muscular movements became less active after the seventh fasting day, but the impression was that of muscular fatigue rather than weakness. The gait was always steady and there was no swaying of the body while standing with the feet together and the eyes closed. The features frequently appeared drawn after the first week, but this was present, as a rule, only during periods of mental depression. The tremor of the hands, the weakness of the muscular movements, and the changes in the voice noted at the end of the fast and after breaking the fast were apparently a part of his hysterical condition. The muddy yellowish tinge to the skin did not change throughout

The conjunctivitis present at the beginning improved slightly after the ninth day of the fast, but was even more marked after the fast was broken, probably because of weeping.

Mouth: The color of the mucous membrane remained good throughout. No change was noted in the teeth (the teeth were not brushed throughout the period of observation). The slight coating on the tongue became more pronounced until the ninth fasting day, when it began to disappear slowly. The tongue did not become entirely clean until the third day after food was taken. On the third day the odor of the breath was offensive, becoming fetid. After the ninth day this was less pronounced and gradually decreased until the twenty-third day, after which time very little odor was noticed.

On the ninth fasting day the mucous membrane of the mouth and lips was dry. On the eleventh day the lips were desquamating (at the same time the seborrhea of the scalp appeared) and this continued until the fifteenth day of the fast and did not occur again. The decrease of these signs promptly followed the prescribed intake of larger quantities of water. No change was noted in the chronic nasopharyngitis.

Glands: No change whatever was noted in the cervical, axillary, epitrochlea glands, or the glands in the groins.

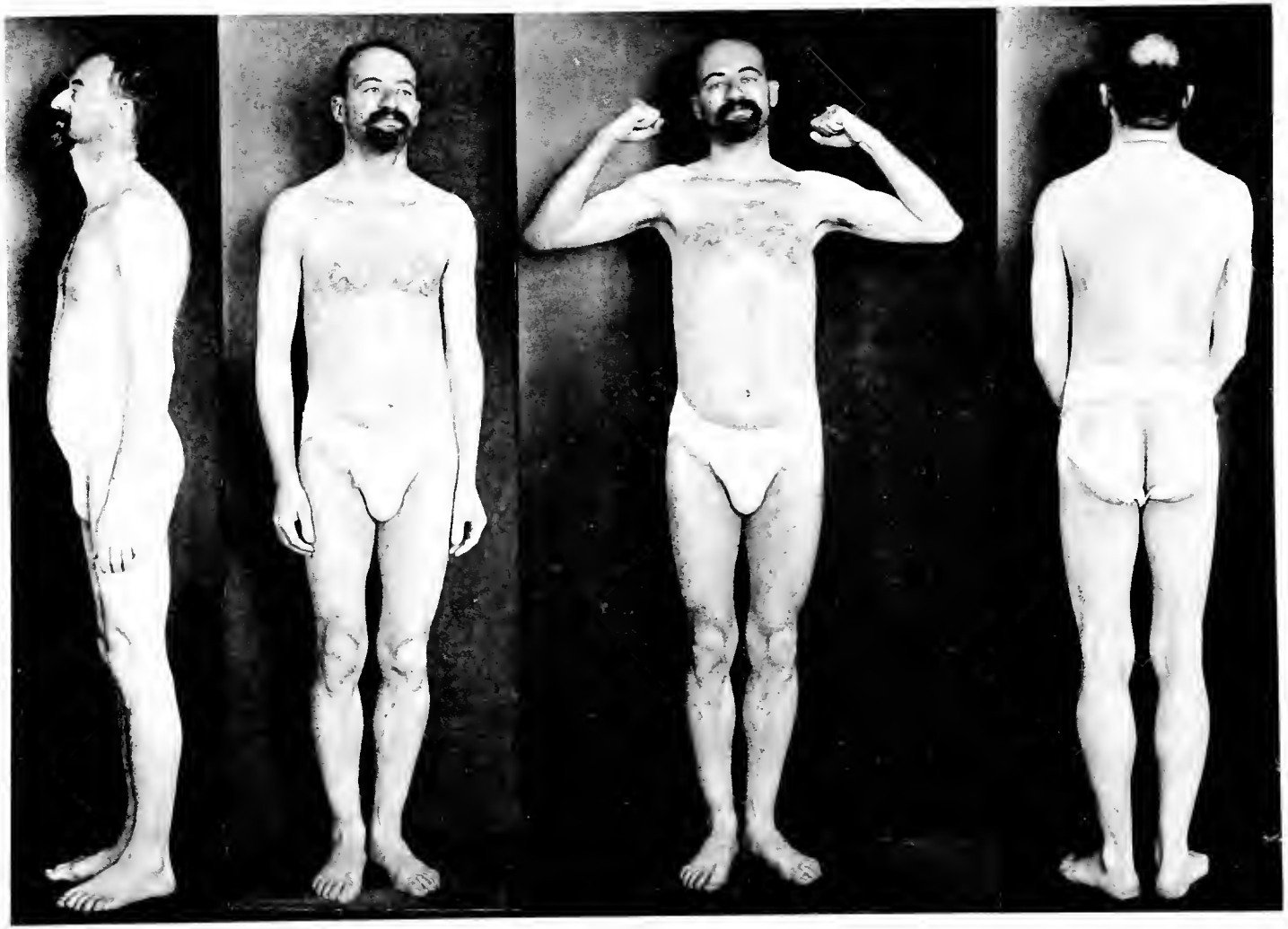
Nervous system: During the first week of the fast the mental attitude was a cheerful one. He was enthusiastic about the experiment but very opinionated. From this time on to the end of the fast he was frequently depressed and sometimes irritable. On these days he was disinclined to talk, his physical movements were more deliberate, and he was more sensitive to any physical discomfort, such as pressure of the hands. He attributed this to the depressive effects of the rain and cloudy weather, but the impression was that he felt actual physical fatigue. On the last day of the fast and for the remaining period of observation he exhibited varying mental states of depression, irritability, and sullenness, weeping at times. Taking the period as a whole there was a gradual increasing depression and irritability, which, with the onset of abdominal pain, manifested itself in hysterical conditions. There was no outward demonstration of any mental improvement as a result of the fast.

Reflexes: The pupillary, plantar, and cremasteric reflexes were normal through the fast. The patella reflex gradually diminished and on the fifth day could only be obtained by re-enforcement and on the ninth day and during the remainder of the fast could not be obtained. The abdominal reflexes were absent on and after the ninth day, and the Achilles on and after the eleventh day. Five months after, the reflexes were normal.

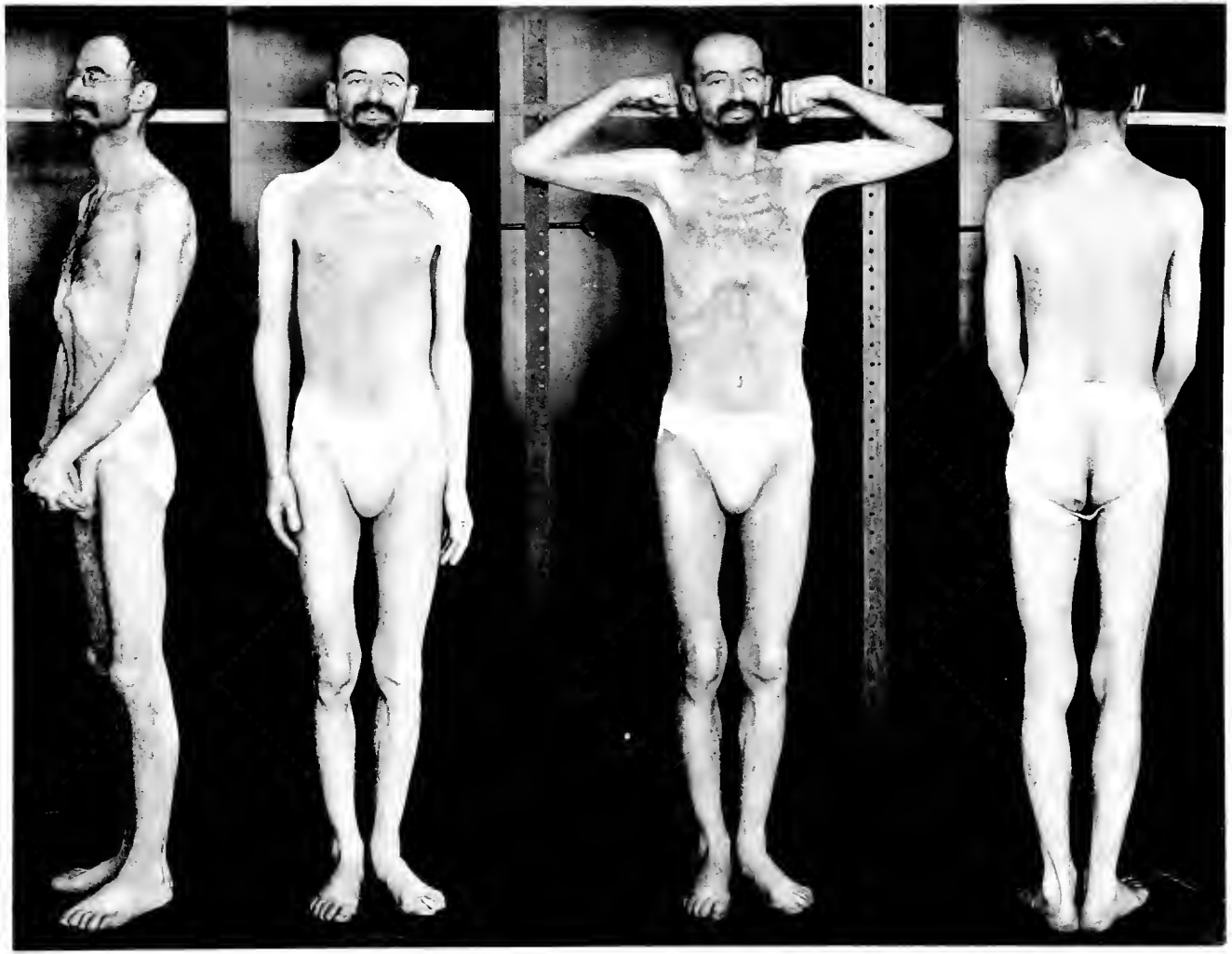
Chest: No change was noted in the chest, with the exception of the gradual sinking in of the supra- and infra-clavicular spaces and the prominence of the ribs as the subcutaneous tissues disappeared.

Lungs: As the loss of tissue in the supra-clavicular space progressed, the percussion note of the apices became slightly higher pitched. The lower border of resonance of the right lung followed the decrease in the size of the liver. No change was noted in the respiratory murmur.

Heart: There was a gradual decrease in the percussion border of the heart noted as follows, the total diminution in size of heart during fast being 4.2 cm.:



Views of subject Levanzin on first day of Thirty-one day Fast



Views of subject Levanzin on last day of Thirty-one day Fast

	From mid-sternum.		Total width.
	Left border.	Right border.	
	cm.	*cm.*	*cm.*
First day of fast,	9.5	1.2	10.7
Seventh day of fast	8.5	1.0	9.5
Ninth day of fast	8.0	1.0	9.0
Seventeenth day of fast	7.5	0.5	8.0
Nineteenth day of fast	7.0	0.0	7.0
Twenty-fifth day of fast	6.8	0.3 to left	6.5
Third day after fast	7.0	0.5 to right	7.5
Fourth day after fast	8.0	0.5 to right	8.5
5 months after fast	9.0	1.5	10.5

Heart sounds: No change was noted in the character of the heart sounds until the eleventh fasting day, when the sounds were less distinct and a systolic souffle was heard all over the præcordia. This souffle was not heard after the fifteenth day, but the sounds remained more distant throughout the fast and after the twenty-fifth day the first sound of the heart was not distinct. After the twenty-third day the aortic second sound was more distinct than the pulmonic second. The systolic souffle appeared at the same period as the seborrhea, the dry mouth, and desquamating lips and disappeared when the water intake was increased.

Abdomen: On the first fasting day most of the gas disappeared from the intestines. The abdomen became retracted and by the fifth day had reached its maximum, the pulsation of the abdominal aorta being pronounced. After this time it was everywhere flat to percussion except over the area of gastric tympany. After the fifteenth day of the fast the contracted large intestines could be palpated along the course of the ascending and descending colon. On the twenty-third, twenty-ninth, and thirty-first days there was a slight gurgling of gas and liquid in the right hypochondrium with pressure.

Twenty-four hours after breaking the fast the ascending colon was distended with gas, but the descending colon was still contracted. On the third day after breaking the fast the whole abdomen was tympanitic and symmetrical.

Liver: A gradual decrease in width of liver dullness as measured in the nipple line was noted, as shown in the table. The total diminution of the width of liver dullness in the nipple line was 5.5 cm. or 47.8 per cent of the total width at the beginning of the fast. On the third day after taking food, the liver was found to be of the same width as at the beginning of the fast.

	Total width.
First day of fast	11.5 cm., edge palpable.
Third day of fast	10.5 cm., edge not palpable.
Fifteenth day of fast	9.5 cm.
Twenty-first day of fast	9.0 cm.
Twenty-fifth day of fast	8.6 cm.
Twenty-ninth day of fast	7.4 cm.
Thirty-first day of fast	6.0 cm.
One day after breaking fast	7.5 cm.
Three days after breaking fast	11.5 cm.
Five months after breaking fast	11.0 cm., edge palpable.

Spleen. No change was noted in the spleen during the fast.

Kidneys: On the thirteenth day of the fast the right kidney was palpable and on the twenty-first the left was palpable and both remained so during the rest of the fasting period. Five months later neither kidney was palpable.

Genital organs: No change noted in the genital organs during the fast.

Observations of the physical condition of Breithaupt, who fasted for 6 days, of Cetti, who fasted for 10 days, and of Beauté, who fasted for 14 days, failed to show any change in the size or position of the organs.

PHOTOGRAPHIC STUDY OF SUBJECT.

The most striking external evidence of prolonged inanition with a fasting subject is the degree of emaciation. In order to visualize this as much as possible as the fast progressed, an extensive series of photographs was taken practically once a week. At these times the calorimeter laboratory was specially warmed with gas stoves, particularly in the part of the room where L. was to pose, and screens were put in place for the background. The subject undressed and put on a small loin cloth; he was then posed on a low pedestal, which was covered with black cloth. In the selection of poses we had the valuable advice of Professor W. G. Anderson, of Yale University.

Probably no routine throughout the whole fast pleased the subject more than this series of photographs, as he seemed obsessed with the desire to have himself photographed. We were accordingly able to obtain a large number of photographs of the subject in a variety of poses. Several of those obtained on the first and last days of the fast are given in Plates 4 and 5. In the latter part of the fast the subject became somewhat less sure of his footing and rested lightly against a wooden frame. A rough approximation of the measurements of this man may be made by using 640 mm. as the inside distance between the wooden uprights. Lack of time prevented our adjusting the accurate mirror arrangement of Friedenthal[1] for securing photographs that could subsequently be measured. It should be considered, however, that the chief reason for taking this series of photographs was to visualize the general appearance of emaciation and not to furnish material for exact measurements of the loss of tissue. This was supplied by the accurate measurements made according to the regular schedule by Professor W. G. Anderson. (See p. 68.)

In addition to the anatomical photographs, a great many photographs were taken of L. at his own desire, since this seemed to be the one thing which would amuse him at any time. Accordingly the camera was pointed at him several hundred times throughout the course of the fast, although admittedly many of these were false exposures. A considerable number of photographs were thus obtained which show him in his environment, some of which are deemed worthy of reproduction (see Plates 1, 2, and 3, pages 11, 19, and 31).

[1]Friedenthal, Med. Klinik, 1909, No. 19, p. 1.

ANTHROPOMETRIC MEASUREMENTS.

The importance of careful anthropometric measurements for noting the diminution in size of the body as the fast progressed has been recognized by all writers on fasting. Fortunately Professor William G. Anderson, of Yale University, was in Boston during the period when this fasting experiment was being made and he kindly offered to make a series of anthropometric measurements of the subject. In this he was assisted by Dr. W. L. Anderson. These measurements were made approximately once a week, Dr. W. L. Anderson making a special trip from New Haven to complete the series at the end of the fast.

Professor Anderson reports that "the measurements of the forearm are taken with the hand tightly closed and the wrist slightly flexed. The measurements of the upper arm are taken at the largest part after the elbow is completely flexed and all flexors and extensors contracted to their utmost. In taking the measurements of the calf and thigh, we select the largest part after the man has contracted the muscles as well as he can while in the standing position."

The measurements for each week are given in table 1, the total decreases in the various girths for the whole fast being given in the last column. As would be expected, the largest change in girth was at the waist, there being a decrease of 153 mm. The girth of the abdomen decreased 119 mm., while a large decrease is shown for both thighs and for the chest. Certain of the measurements were not made until the second or third examination; the losses are therefore inclosed in parentheses to indicate that the series of measurements was not complete. The distinct loss in practically all measurements is obvious.

In the hope of securing some evidence in regard to the muscular strength of the subject, Professor Anderson brought with him his dynamometers to test the strength. To our great surprise, the subject even before the fast began refused to carry out any of these tests, stoutly maintaining that he was not an athlete but a professional gentleman and that he was not accustomed to doing muscular work of any kind. This was wholly in line with his attitude toward other muscular-work tests which were contemplated, but which it was necessary to omit, greatly to our regret. The only evidence that we have regarding the muscular strength of the subject is the material obtained in the dynamometer tests which were secured every afternoon by Professor Langfeld. Even regarding these we are somewhat uncertain as to whether the subject exerted his greatest strength in all the tests. The pressure which he placed upon the dynamometer was clearly influenced by his fear that such pressure might give him a little pain, to which he was strongly averse.

TABLE 1.—*Measurements of subject L.*

Measurement.	April 11, 1912.	April 18, 5th day of fast.	April 25, 12th day of fast.	May 2, 19th day of fast.	May 8, 25th day of fast.	May 14, 31st day of fast.	Total loss.
Height:	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Standing	1707	1707	1707	1704	1707	1707	0
Sitting	....	....	874	884	884	881	(—7)
Girth:							
Neck	376	371	368	361	338	335	41
Chest, normal	879	871	856	825	805	800	79
full	930	937	904	876	864	851	79
empty	828	823	813	792	787	782	46
Ninth rib, full	874	881	866	848	825	820	54
empty	787	787	775	767	759	754	33
Tenth rib	...	785	770	762	749	749	(36)
Abdomen	800	785	742	757	686	681	119
Waist	780	749	696	673	648	627	153
Hips	...	....	....	813	805	792	(21)
Right biceps, extended	251	241	234	226	221	211	40
flexed	279	269	259	249	236	239	40
Right forearm, extended	254	244	236	234	229	224	30
Left biceps, extended[1]	254	251	241	229	224	218	36
flexed	284	272	267	262	246	239	45
Left forearm, extended	262	254	246	241	241	229	33
Right thigh	488	465	450	432	427	394	94
Right calf	335	335	323	310	305	300	35
Left thigh	488	470	457	432	406	399	89
Left calf	345	338	320	315	302	295	50
Breadth:							
Shoulders	...	....	419	424	417	419	(0)
Chest, full	...	....	279	272	269	254	(25)
empty	...	....	254	254	254	239	(15)
Hips	...	....	312	307	282	279	(33)
Depth:							
Chest, full	254	251	241	241	229	229	25
empty	...	....	211	211	201	203	(8)
Abdomen	188	183	163	160	170	152	36

[1]The subject was left-handed.

BODY-WEIGHT.

To the ordinary individual the most striking index of the severity of a prolonged fast is the loss in body-weight, the abstinence from food resulting in great emaciation. The fact that even in the short space of 24 hours the body-weight changes considerably is not so patent, and a consideration of these changes is of interest. If the body-weight is determined each hour throughout the day, it will be seen that while sudden fluctuations accompany the ingestion of food, the voiding of urine, or the passing of feces, there is a general tendency for a regular fall in the body-weight from hour to hour amounting, with adults, to not far from 40 grams per hour.[1] During the night, the decrease in the body-weight is regular, although not quite so rapid. Since such a tendency is shown in the course of 24 hours, it would normally be expected that it would be more especially evident in the 20 or 30 days of a fast and that the body-weight would decrease steadily as the fast progressed.

ROUTINE OF OBSERVATIONS.

The losses in body-weight have usually been recorded in every reported fast, whether scientifically controlled or not. Unfortunately, however, the observations vary in value, as the weighings have not always been made under constant conditions. At times they even show a gain rather than a loss. Comparable results in such observations may be secured by the following routine:

The weights should be taken at approximately the same time each day.
If the subject is not weighed nude, the clothing worn should be approximately of the same weight, and its weight should be deducted from the total weight recorded, thus giving the true value for the body-weight of the subject.
The bladder should always be emptied immediately or a short time before the weighing.
The amount of drinking water taken prior to the weighing should be constant.
No water should be taken for some hours before the observation is made.
The weighings should always be made on the same carefully calibrated scales and should be checked by a second observer.
The environmental temperature and the muscular activity should be approximately constant throughout the whole period of the fast.

As usually fasting subjects are very captious, investigators are ordinarily content to control them only in so far as the collection of the excreta and the abstinence from food are concerned, without rigorously insisting upon their remaining in a quiet, closed room during

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, p. 113. Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 90.

the whole period of the fast, with a constancy in the muscular activity. In the long fasting experiment with L., however, the routine for weighing previously outlined was followed very closely.

The subject emptied the bladder immediately after leaving the bed calorimeter each day about 8 a. m. A respiration experiment of three or four 15-minute periods was next made with him. This was usually finished about $9^h\ 30^m$ a. m. He was then carefully weighed on a calibrated platform balance, the weighings and records being made by Mr. Carpenter and checked by a second observer. (See plate 2, figure D, page 19.) The scales used were the so-called "silk" scales, capable of weighing 150 kilograms with a sensitivity of 10 grams with a full load. The temperature of the calorimeter room was rarely below 20° C., but as the subject was used to a warmer climate he was especially sensitive to cold. He was therefore not weighed nude, but in a cotton union suit and socks which had been washed in distilled water. He also wore over this union suit his heavy woolen underwear. The exact weight of this clothing was known and deducted from the weight shown on the scales. It was not practicable to make the weighing directly after he had emptied the bladder, as it seemed undesirable to have him stand so long before the respiration experiment began.

No water was taken during the night, so that when the subject was weighed he had been without water for some 12 hours. Furthermore, the amount of water taken during the day was approximately constant in quantity, *i. e.*, for the first 10 days of the fast 750 c. c. and for the remaining days 900 c. c. During the night the subject had remained in the calorimeter chamber under constant temperature conditions, and as he usually lay very quietly, the activity was at a minimum. While the temperature conditions and muscular activity necessarily varied somewhat during the day, they were fairly constant, especially as the subject was by nature averse to muscular activity.

As L. was extremely interested in the records of the body-weight from day to day, the change in weight was computed and roughly plotted daily in the form of a curve on the blackboard in the calorimeter laboratory. Any irregularities in the curve would be instantly detected and verifications made if necessary. As a matter of fact, such verification never indicated a discrepancy and we have the fullest confidence in this series of weights.

While the time relations were not theoretically ideal, they were as nearly so as was practicable with the large number of observations necessary to be made simultaneously upon this man. A sample day's computation of the loss of weight is as follows:

	kilos.
Body-weight in cotton underwear, socks, and heavy woolen underwear, $9^h\ 35^m$ a.m., April 20, 1912	57.37
Weight of cotton underwear and heavy woolen underwear	1.48
Naked body-weight, $9^h\ 35^m$ a.m., April 20, 1912	55.89
Naked body-weight, $9^h\ 40^m$ a.m., April 19, 1912	56.37
Loss in body-weight, April 19–20, 1912	0.48

DAILY LOSSES IN BODY-WEIGHT IN FASTING EXPERIMENTS.

The loss in body-weight in fasts of short duration has been extensively discussed in a former publication.[1] Since the appearance of this book, several other fasts have been reported which were but superficially mentioned there. We have accordingly gathered together in table 2 the records of body-weight obtained in a considerable number of fasting experiments continuing 14 days or more. The largest number of fasting experiments with any one man has been made with the professional faster, Succi. The scientific aspects of these experiments have become world-renowned by means of the classical research of Luciani,[2] which was carried out in Florence in 1890 and has never been equaled as a careful analytical study of prolonged fasting. In the course of this report it will be occasionally necessary to call into question Luciani's conclusions, but the reader is particularly requested to consider that since the publication of Luciani's work a quarter of a century has passed and that the criticisms raised must be chiefly of the technique rather than of the interpretation of the results by the Italian master.

Table 2 includes not only the data for the seven fasts of Succi, but also the records of the body-weights secured for three other individuals, *i. e.*, Jacques, Beauté, and the fasting woman Schenk. In examining these records, it will be seen that in some of the experiments Succi had a body-weight some 13 or 14 kilograms greater than in others. Several of these observations also show actual gains in weight, as, for instance, two records in Succi's fast in Florence, one record in the Naples fast, and five records for the fasting man Jacques. Usually the protocols for the experiments explain these apparent gains as being due to changes in the amount of water consumed or in the time of weighing.

An examination of the losses of weight in these fasts shows that in general the larger losses were found in the first days of the fast, although on the twelfth day of the Paris fast and the eleventh day of the Milan fast, Succi lost more than 1 kilogram of weight. The usual losses in the later days of the fast were from 300 to 400 grams in a day. Although occasionally records are found of a loss of only 100 grams or less in a day, such values are open to suspicion and are generally accounted for by errors in weighing or lack of control of conditions. These minimum losses are by no means *a priori* evidence that the fast was not genuine so far as abstinence from food was concerned, since irregularities in the amount of drinking water and particularly in the length of time intervening between the drinking of water and the weighing, irregularities in the voiding of urine as compared with the time of weighing, and

[1]Benedict, Carnegie Inst., Wash. Pub. No. 77, 1907, p. 301.

[2]Luciani, Fisiologia del digiuno. Florence, 1889. Das Hungern. Translation by M. C. Fraenkel. Hamburg and Leipsic, 1890.

changes in the environmental temperature or muscular activity will of course increase or decrease the regular loss of material.

Table 2 also gives the records of the body-weights obtained in the fasting experiment with our own subject L. The greatest loss shown during the 31 days of the fast was 1.04 kilograms on the first day and the smallest loss in weight was 0.11 kilogram on the thirteenth day.

TABLE 2.—*Losses of body-weight by fasting subjects, with initial weight and weight on each day of fast.*

(Weight given in kilograms.)

Day of fast.	Succi.													
	Paris, 1886.		Milan, 1886.		Florence, 1888.		London, 1890.		Naples, 1892.		Rome, 1893.		Zurich, 1896.	
	Wt.	Loss.	Wt.	Loss.	Wt.	Loss.	Wt.	Loss.	Wt.	Loss.	Wt.	Loss.	Wt.	Loss.
Initial wt.	.....	.....	.....	.....	63.30	.....	.....	.....	.....	.....	65.10	.....	71.70	.....
1st.	63.00	.....	61.30	.....	62.40	0.90	55.80	.....	63.60	.....	64.70	0.40	.....	.....
2d.	59.40	3.60	59.75	1.55	61.00	1.40	54.90	0.90	61.80	1.80	64.00	.70	.....	.....
3d.	59.00	.40	58.95	.80	59.80	1.20	53.90	1.00	60.60	1.20	63.30	.70	68.50	3.20[1]
4th.	58.00	1.00	58.20	.75	59.90	+.10	52.80	1.10	59.80	.80	62.80	.50	68.00	.50
5th.	57.40	.60	57.70	.50	59.30	.60	52.10	.70	59.10	.70	61.20	1.60	67.55	.45
6th.	57.10	.30	56.85	.85	58.65	.65	51.50	.60	58.20	.90	60.90	.30	67.25	.30
7th.	57.00	.10	56.30	.55	58.15	.50	51.00	.50	57.50	.70	60.70	.20	66.55	.70
8th.	56.90	.10	56.10	.20	57.65	.50	50.40	.60	57.10	.40	59.30	1.40	.....	.....
9th.	56.00	.90	55.60	.50	57.25	.40	50.10	.30	56.90	.20	59.10	.20	65.70	.85[2]
10th.	55.70	.30	55.40	.20	56.70	.55	49.80	.30	57.20	+.30	59.00	.10	65.40	.30
11th.	55.30	.40	54.40	1.00	56.25	.45	49.70	.10	56.50	.70	59.00	.00	65.00	.40
12th.	54.00	1.30	54.30	.10	55.60	.65	49.30	.40	55.90	.60	58.90	.10	64.55	.45
13th.	53.20	.80	54.00	.30	55.25	.35	48.90	.40	55.50	.40	58.55	.35	64.05	.50
14th.	.....	.....	53.60	.40	54.85	.40	48.70	.20	55.40	.10	58.20	.35	.....	.....
15th.	53.00	.20[2]	53.10	.50	54.60	.25	48.30	.40	55.30	.10	58.00	.20	63.50	.55[2]
16th.	52.70	.30	52.85	.25	54.30	.30	48.10	.20	55.25	.05	57.80	.20	63.00	.50
17th.	52.50	.20	52.60	.25	54.10	.20	47.55	.55	54.60	.65	57.60	.20	62.75	.25
18th.	52.20	.30	52.10	.50	53.65	.45	47.25	.30	54.00	.60	57.50	.10	62.50	.25
19th.	51.90	.30	51.35	.75	53.20	.45	47.10	.15	53.50	.50	57.05	.45	62.20	.30
20th.	51.60	.30	51.15	.20	52.80	.40	46.80	.30	53.00	.50	56.50	.55	61.90	.30
21st.	51.20	.40	50.90	.25	52.60	.20	46.50	.30	52.40	.60	.....	.....	.....	.....
22d.	.....	.....	50.90	.00	52.25	.35	46.30	.20	.....	.....	.....	.....	.....	.....
23d.	50.75	.45[2]	50.60	.30	51.85	.40	45.90	.40	.....	.....	.....	.....	.....	.....
24th.	50.20	.55	50.15	.45	51.45	.40	45.60	.30	.....	.....	.....	.....	.....	.....
25th.	50.10	.10	49.70	.45	51.50	+.05	45.40	.20	.....	.....	.....	.....	.....	.....
26th.	50.00	.10	49.40	.30	51.30	.20	45.20	.20	.....	.....	.....	.....	.....	.....
27th.	49.65	.35	49.00	.40	51.25	.05	44.90	.30	.....	.....	.....	.....	.....	.....
28th.	49.50	.15	48.70	.30	51.05	.20	44.60	.30	.....	.....	.....	.....	.....	.....
29th.	49.25	.25	48.50	.20	50.45	.60	44.30	.30	.....	.....	.....	.....	.....	.....
30th.	48.75	.50	48.20	.30	.....	.....	44.20	.10	.....	.....	.....	.....	.....	.....
31st.	.....	.....	.....	.....	.....	.....	44.10	.10	.....	.....	.....	.....	.....	.....
32d.	.....	.....	.....	.....	.....	.....	43.80	.30	.....	.....	.....	.....	.....	.....
33d.	.....	.....	.....	.....	.....	.....	43.70	.10	.....	.....	.....	.....	.....	.....
34th.	.....	.....	.....	.....	.....	.....	43.50	.20	.....	.....	.....	.....	.....	.....
35th.	.....	.....	.....	.....	.....	.....	43.20	.30	.....	.....	.....	.....	.....	.....
36th.	.....	.....	.....	.....	.....	.....	43.00	.20	.....	.....	.....	.....	.....	.....
37th.	.....	.....	.....	.....	.....	.....	42.75	.25	.....	.....	.....	.....	.....	.....
38th.	.....	.....	.....	.....	.....	.....	42.60	.15	.....	.....	.....	.....	.....	.....
39th.	.....	.....	.....	.....	.....	.....	42.30	.30	.....	.....	.....	.....	.....	.....
40th.	.....	.....	.....	.....	.....	.....	41.70	.60	.....	.....	.....	.....	.....	.....

[1] Loss for 3 days.

[2] Loss for 2 days.

TABLE 2.—*Losses of body-weight by fasting subjects, with initial weight and weight on each day of fast*—Continued.

(Weight given in kilograms.)

Day of fast.	Jacques, 1888.		Beauté, 1907.		Schenk, 1906.		L., 1912.	
	Weight.	Loss.	Weight.	Loss.	Weight.	Loss.	Weight.	Loss.
Initial wt...	62.01	....	65.61	....	56.3	....	60.64	....
1st.....	60.68	1.33	64.57	1.04	54.4	1.90	59.60	1.04
2d.....	59.74	.94	63.72	.85	53.6	.80	58.68	.92
3d.....	59.23	.51	62.77	.95	53.2	.40	57.79	.89
4th.....	59.24	+.01	61.96	.81	52.5	.70	57.03	.76
5th.....	58.98	.26	61.41	.55	51.9	.60	56.37	.66
6th.....	58.35	.63	60.83	.58	51.2	.70	55.89	.48
7th.....	58.55	+.20	60.23	.60	50.9	.30	55.50	.39
8th.....	56.68	1.87	60.04	.19	50.6	.30	55.08	.42
9th.....	56.23	.45	59.80	.24	50.5	.10	54.63	.45
10th.....	56.23	.00	59.11	.69	50.2	.30	54.13	.50
11th.....	55.80	.43	58.64	.47	49.9	.30	53.88	.25
12th.....	55.60	.20	58.64	.00	49.5	.40	53.56	.32
13th.....	54.67	.93	58.37	.27	49.1	.40	53.45	.11
14th.....	54.67	.00	57.78	.59	48.8	.30	53.15	.30
15th.....	55.04	+.37	.....	....	48.4	.40	52.84	.31
16th.....	54.98	.06	.....	....	48.2	.20	52.26	.58
17th.....	55.06	+.08	.....	....	....	....	51.79	.47
18th.....	54.81	.25	.....	....	....	....	51.50	.29
19th.....	53.93	.88	.....	....	....	....	51.11	.39
20th.....	53.93	.00	.....	....	....	....	50.93	.18
21st.....	53.82	.11	.....	....	....	....	50.49	.44
22d.....	53.36	.46	.....	....	....	....	50.13	.36
23d.....	53.00	.36	.....	....	....	....	49.96	.17
24th.....	52.74	.26	.....	....	....	....	49.62	.34
25th.....	52.46	.28	.....	....	....	....	49.33	.29
26th.....	52.40	.06	.....	....	....	....	49.02	.31
27th.....	51.89	.51	.....	....	....	....	48.70	.32
28th.....	52.23	+.34	.....	....	....	....	48.46	.24
29th.....	51.86	.37	.....	....	....	....	48.10	.36
30th.....	51.69	.17	.....	....	....	....	47.69	.41
31st.....	.....	....	.....	....	....	....	47.39	.30

Every effort was made to secure uniformity of conditions throughout this fast, and probably in no long fast with man have these ideal conditions been so nearly approached. Yet, even with this care, it will be seen that the losses were by no means regular from day to day, although the variations are not so great as in the other fasts referred to in table 2.

Unquestionably the loss in weight in a strictly controlled fast may be considered a good general measure of the intensity of metabolic processes; yet with such wide fluctuations as are shown for L. it hardly seems probable that the body-weight can be looked upon as an accurate index of the total tissue change. But attempts have frequently been made by investigators to establish a mathematical relationship between the daily loss in weight and the length of the fast. Luciani, basing his conclusions upon the results of his study with Succi in Florence and particularly upon two long experiments with dogs, was confident that such a mathematical relationship existed. To study the possibilities

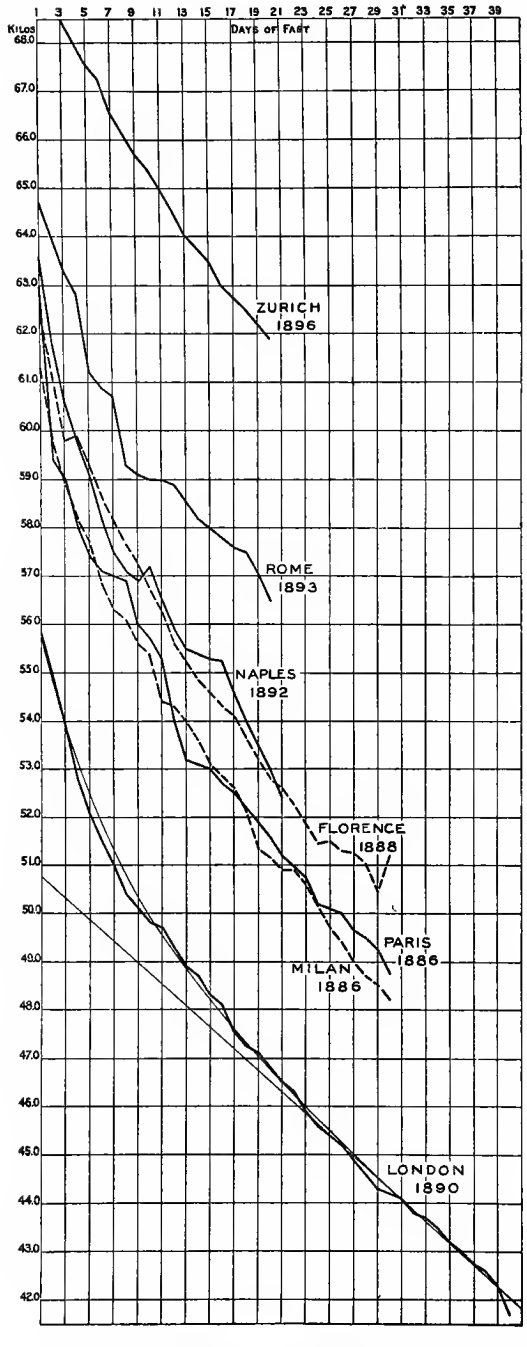


FIG. 1.—Body-weight curves for fasting experiments with Succi.

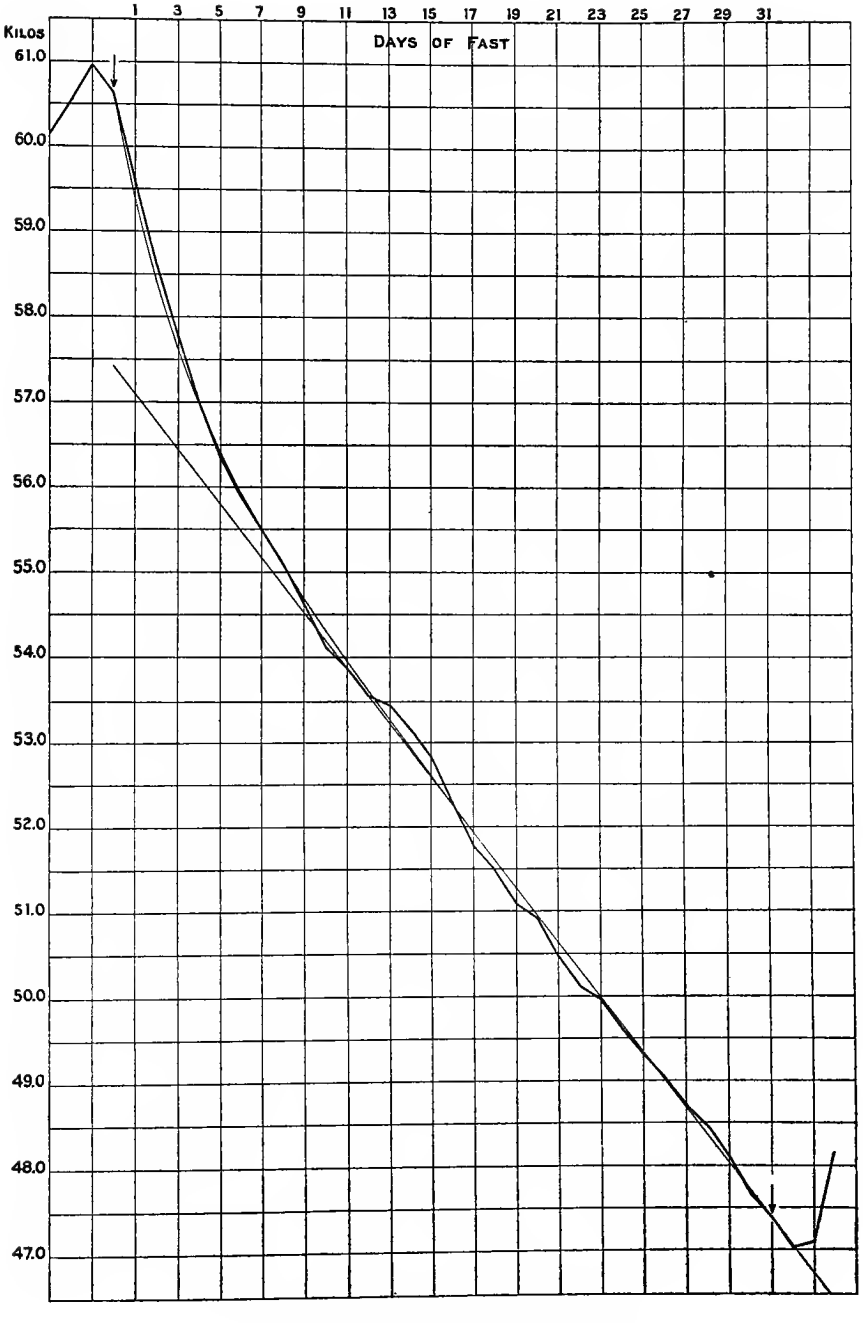


FIG. 2.—Body-weight curve for Levanzin.

of this relationship, curves have been plotted showing graphically the changes in weight during each of Succi's fasts. (See figure 1.) A similar curve has been plotted showing the records of body-weights during the fasting experiment with L. (See figure 2.)

If we analyze the components which make up the loss in weight of the body, we find it is due not only to the loss of body tissue which is oxidized to supply material for the maintenance of the body activity, but to the loss of preformed water, *i. e.*, the water existing in the tissues oxidized. According to observations in some of the earlier fasting experiments in Middletown, Connecticut, this preformed water, which varies widely in amount, appears to be rapidly discharged in the first days of fasting. We would consequently expect to find that the curves for a fasting experiment would indicate a rapid fall in weight at the beginning of the fast, the percentage loss becoming gradually smaller, until the body-weight curve tends to become a straight line. If the curves for Succi and Levanzin are examined, this tendency will be seen. On the other hand, while all the curves have the same general trend, a careful mathematical analysis shows no regularity that would justify the use of a mathematical expression by means of which losses of weight may be predicted during prolonged fasts. When one considers that only the Florence fast was controlled by Luciani, and that the others were made in different years, at different seasons, and in different countries, it will be seen that but little can be expected from a comparison of these curves.

Nevertheless, the semblance of mathematical regularity shown in the records of body-weight obtained in Succi's Florence fast and in the experiments with dogs led Luciani to seek the aid of his associate, Bufalini, who computed that the body-weight curves, especially those obtained in experiments on dogs, (see P and P′ on figure 3) had a tendency to represent an equilateral hyperbola. Reasoning from the equilateral hyperbola equation obtained with dogs, Luciani computed the probable curve for Succi's weights during the Florence fast and found that the loss in weight was very much less than he would have expected. He interpreted this as being due to the fact that Succi drank much larger amounts of water than did the dogs and that water apparently acted as a nutrient, thus sparing the tissues.

Since a reasonable regularity was also shown in the course of the curve obtained for L., a probable curve for this subject was developed by Mr. E. H. Lange, physicist of the Nutrition Laboratory. (See curve in light line in figure 2.) Using W to represent the weight in kilograms and T the time in days, the weight for any given day is found by the formula:

$$W = 3.20\ (10)^{-0.143T} - 0.324T + 57.43$$

A similar equation has been worked out for Succi's London fast, as follows:

$$W = 4.98\ (10)^{-0.0692T} - 0.222T + 50.75$$

(See curve in light line in fig. 1.) Obviously such a complicated curve can not in any wise be considered a simple mathematical relationship.

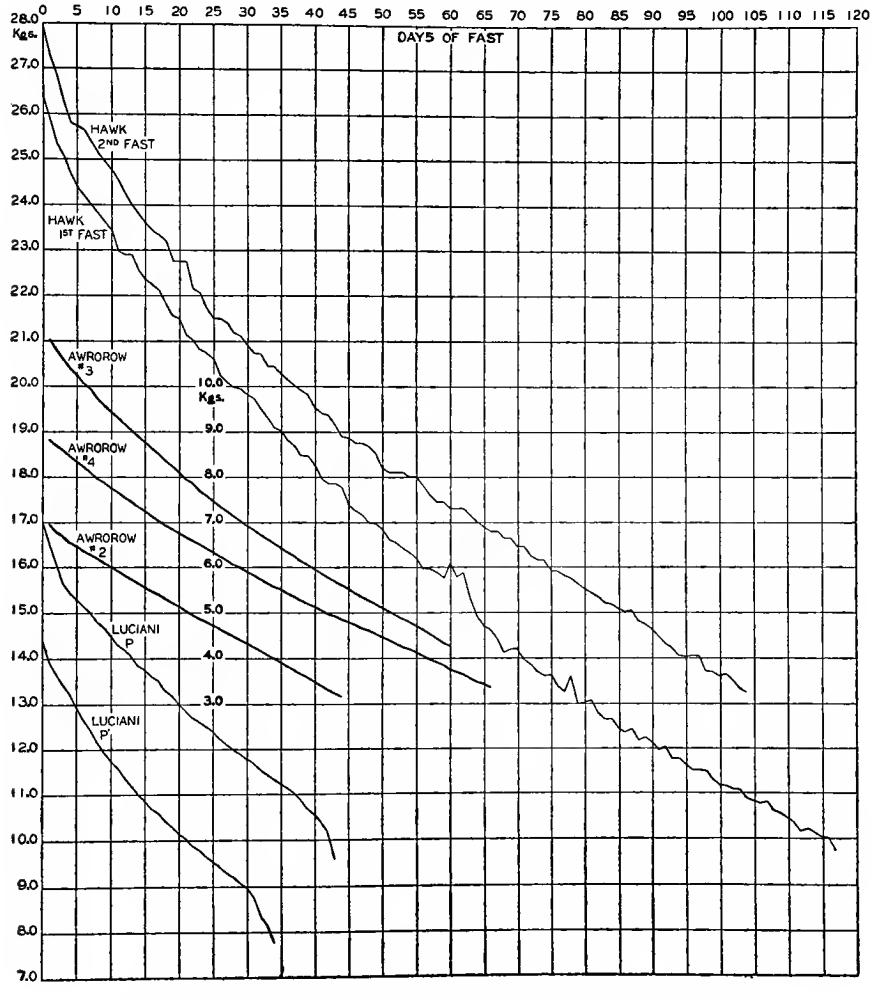


FIG. 3.—Body-weight curves for prolonged fasting experiments with dogs.

Ideal conditions for studying the loss in weight during fasts would be those in which the subject had a constant amount of drinking water, emptied the bladder completely at a definite period each day, remained in an absolutely constant environment with a constant temperature,

and the metabolism pursued a course entirely unaffected by extraneous conditions. Such constant conditions are impracticable with human beings, but are more easily obtained with animals. Several remarkably long fasting experiments have been made with dogs, but the records are for the most part not easily accessible. Curves showing the records of body-weight in these animal experiments are given in fig. 3. The body-weights obtained by Luciani on two dogs, one in Siena and another in Florence, are represented by the curves designated as P and P′. These dogs were catheterized each day, were given exactly 150 c. c. of water daily, and were kept in a room free from disturbance of any kind and in a temperature of approximately 12° to 13° C. It will be seen that the loss in weight follows a fairly regular course, save on the last few days of each fast, none of the irregularities shown in the body-weights of Succi and our subject L. being apparent.

Luciani's two experiments with dogs continued 34 and 43 days respectively, but still longer experiments have been made by P. B. Hawk, in which a dog fasted in two experiments of 117 and 104 days respectively. The complete results of these experiments have not yet been published,[1] but the investigator has kindly given me the privilege of using certain of the data in this connection. The body-weights obtained during these fasts are also shown in figure 3. The amount of drinking water given to the dog was constant, but the animal was not kept in a chamber with even temperature and the other conditions were not so well controlled as in Luciani's experiments, as the purposes of the fasts were entirely different. Aside from slight fluctuations, however, the curves follow a reasonably constant course. These curves are of particular value owing to the extraordinary length of the fasting periods.

A series of observations made by Awrorow on dogs with complete fasting is of even more interest in studying this specific problem. The dogs were confined in the Pashutin respiration chamber in the Imperial Medical Academy in St. Petersburg, receiving neither food nor water. They were catheterized daily, weighed at a regular hour, and spent 22 or more hours out of the 24 hours in the quiet and isolation of the respiration chamber, during which the carbon-dioxide production was carefully measured. The period of fasting with the four dogs continued for 16, 44, 60, and 66 days respectively. Under these conditions one would expect a most regular progress in the metabolism, with constant loss of water and organic material, and changes in the body-weight. That this is true to a marked extent is shown from an examination of the three curves for the dogs which fasted the longest, *i. e.*, 44, 60, and 66 days. The striking regularity of these curves bears out completely Professor Luciani's view that if such experimental con-

[1]Howe and Hawk, Am. Journ. Physiol., 1912, **30**, p. 174; Howe, Mattill, and Hawk, Journ. Biol. Chem., 1912, **11**, p. 103.

ditions can be secured in a fasting experiment, the curve will be extraordinarily regular.[1]

As an effort was made to secure constant conditions in the experiment with our fasting subject, it was hoped that a curve approximating the regularity of the curve for Awrorow's dogs could be obtained, but an examination of the plotted values for the daily body-weights shows that this was far from being the case. It would be practically impossible to carry out a lengthy fasting experiment with a man with environmental conditions as constant as were those of the dogs used by Awrorow. We know also that the loss of material varies greatly both in amount and in kind with the progress of the fast. Thus there is always greater metabolism, greater activity, and a greater disintegration of material in the first few days of fasting. As the fast progresses, the effect becomes more or less noticeable, and the subject becomes disinclined to active muscular work, thus naturally conserving his energy. Furthermore, human subjects, by covering themselves with extra clothing and preferring warm rooms, attempt to conserve their calorific output.

The character of the katabolism may also vary greatly, particularly during the first few days of the fast, so that there is unquestionably a rapid depletion of the glycogen storage in the body in this period. The course of the curve would therefore vary according to whether the subject of the experiment was well nourished, poorly nourished, or obese. The character of the foregoing diet may likewise play a role in this connection. It will be seen later, however, when a study is made of the gaseous metabolism during the fast, that the possibility for analyzing the daily losses in a fast such as that carried out by L. are much greater than in any fasting experiment thus far observed with man, and that no mathematical relationship between the length of time of a human fast and the loss in body-weight can be expected.

[1]The data for these curves were secured from the large work on fasting dogs written by Professor Awrorow. Curves showing the percentage loss of body-weight for two of these dogs are shown on two lecture charts kindly given me by Professor Awrorow during my 1907 visit to St. Petersburg, and reproduced in figures 45 and 46 on pages 356 and 357 of this report.

While this report on the long fasting experiment made in the Nutrition Laboratory is designed primarily to deal only with the influence of prolonged fasting on human metabolism, it will not be out of place here to emphasize the fact that a colossal amount of research on fasting animals has been accumulating in the laboratories in St. Petersburg for a number of years, chiefly under the direction of Albitsky. A considerable portion of this material was incorporated in the second volume of Pashutin's experimental pathology, of which 840 pages are devoted to the discussion of fasting. This material has been considered so important to workers in metabolism that it has been translated in the Nutrition Laboratory and typewritten copies of the translation have been deposited in the library of the Office of the Surgeon-General of the Army, in Washington, D. C., the John Crerar Library in Chicago, Illinois, and the New York Public Library in New York City, the fourth copy being retained by the Nutrition Laboratory.

In addition to this material in Pashutin's book, much of which is recorded for the first time, there are a number of large monographs published by Awrorow, Kartaschefsky, Albitsky, and Likhatcheff, which deal with the abstract problems of metabolism and which have been translated in whole or in part for this laboratory. It is greatly to be regretted that this collection of data, which far exceeds both in quality and amount the total accumulation of earlier investigators on fasting animals, should be so inaccessible to American, English, and Continental readers. It is certainly true that no one working on the gaseous metabolism of animals can at the present day afford to overlook this wonderful collection of Russian material.

TOTAL LOSS IN BODY-WEIGHT.

An examination of the data in table 2 for the subjects other than L. show apparent discrepancies in the initial weights and in the loss of weight on the first day. The exact length of the fasting period and the weight on the last day are also frequently doubtful. The Florence weights were all taken from the plates at the end of Luciani's report "Fisiologia del digiuno." It is obviously important to note whether the initial weight was taken immediately after the meal or before the meal, or what was the condition of the alimentary tract. With our subject L. we believed it to be necessary to obtain an accurate weight at the beginning of the fast; consequently the *initial* weight was taken approximately 12 hours after the last meal, several hours after drinking water, and a definite time after urinating. Such precautions were not taken, we believe, with any of the other subjects given in table 2, with the possible exception of Cathcart's subject, Beauté.

The total losses in the various fasts, particularly when computed as percentages of the initial weights, have certain features that are not without interest. For comparison we give in table 3 the total loss and the percentage loss for each subject at the end of 14, 16, 20, 29, 30, 31, and 40 days respectively (using the data recorded in table 2). Obviously a comparison can be made for all of the subjects for only 14 days, with all the subjects but one for 16 days, with all the subjects but two for 20 days, and finally with but one subject for 40 days. At the end of 14 days the average percentage loss was 12.6 per cent. The lowest loss was with Succi, in the Rome fast, of 10.6 per cent; and the highest loss was 15.7 per cent with the same subject, in the Paris fast. For

TABLE 3.—*Summary of losses of body-weight by fasting subjects.*

Subject.	14 days.		16 days.		20 days.		29 days.		30 days.		31 days.		40 days.	
	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.
Levanzin..	7.49	12.4	8.38	13.8	9.71	16.0	12.54	20.7	12.95	21.4	13.25	21.9	.....	.....
Succi:														
Paris....	9.90	15.7	10.30	16.3	11.40	18.1	13.75	21.8	14.25	22.6	.....	.....	.....	.....
Milan...	7.70	12.6	8.45	13.8	10.15	16.6	12.80	20.9	13.10	21.4	.....	.....	.....	.....
Florence.	8.45	13.3	9.00	14.2	10.50	16.6	12.85	20.3	.....	.....	.....	.....	.....	.....
London..	7.10	12.7	7.70	13.8	9.00	16.1	11.50	20.6	11.60	20.8	11.70	21.0	14.10	25.3
Naples..	8.20	12.9	8.35	13.1	10.60	16.7	.....	.....	.....	.....	.....	.....	.....	.....
Rome...	6.90	10.6	7.30	11.2	8.60	13.2	.....	.....	.....	.....	.....	.....	.....	.....
Zurich...	7.95	11.1	8.70	12.1	9.80	13.7	.....	.....	.....	.....	.....	.....	.....	.....
Jacques....	7.34	11.8	7.03	11.3	8.08	13.0	10.15	16.4	10.32	16.6	.....	.....	.....	.....
V. Beauté..	7.83	11.9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Schenk....	7.50	13.3	8.1	14.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average.	.....	12.6	.....	13.4	.....	15.6	.....	20.1	.....	20.6	.....	21.5	.....	25.3

16 days the average percentage loss was 13.4 per cent, the lowest again appearing with Succi in the Rome fast of 11.2 per cent and the highest 16.3 per cent in the Paris fast. For 20 days the average percentage loss was 15.6 per cent, the lowest being with Jacques of 13 per cent, and the highest 18.1 per cent with Succi in the Paris fast. For 29 days the average loss was 20.1 per cent, the lowest again being with Jacques of 16.4 per cent and the highest 21.8 per cent in the Paris fast of Succi. For 30 days the average value was 20.6 per cent, the lowest being with Jacques, of 16.6 per cent, and the highest 22.6 per cent in the Paris fast of Succi. For 31 days only two experiments were comparable, the percentage loss in both of these being about 21 per cent, while in the 40-day experiment the percentage loss was 25.3 per cent. Of special interest is the fact that, aside from the fast with Jacques, in which the weights of the drinking water and urine were perhaps less trustworthy than in the other fasts, it can be said that at the end of 30 days of fasting, 21.5 per cent of the initial body-weight was lost. This is strikingly regular in the fasts of both Succi and Levanzin. The maximum loss of weight recorded in any controlled fasting experiment with man was in the London fast with Succi, when at the end of 40 days a loss of 25.3 per cent of the initial body-weight was shown.

In contrast with these values found with man are the losses found with animals, when the degree of emaciation has been carried to an extreme and, indeed, in some instances to the point of death. In Hawk's first fasting experiment, in which the dog fasted 117 days, 62.9 per cent of the initial body-weight was lost. The dog recovered, was fed, and later underwent a second fast of 104 days, in which he lost 52.5 per cent of the initial body-weight and then suddenly died. Hawk's dog lived in the laboratory and was given a definite amount of water, but Awrorow's dogs received neither food nor water, and the fasting was carried to the point of death. With dog No. 2 the fast lasted 44 days, with a loss of 55 per cent of the initial body-weight. With dog No. 3 the fast continued 60 days, with a loss of 61.6 per cent, while with dog No. 4 the fast was 66 days in length, with a loss of 62.0 per cent of the initial body-weight. Still other values were obtained by Luciani with the two dogs which fasted under special experimental conditions. As shown in his curve,[1] the dog P lost 43.5 per cent of his initial body-weight in a 43-day fast, while the dog P′ lost 45.5 per cent in a 34-day fast.

Incidentally it should be mentioned that Gayer, in his 30-day fast in New York in 1912, was said to have lost 17.4 per cent of his initial weight of 210 pounds (95.3 kilograms), while Penny, in his self-controlled fast of 30 days, lost 19 per cent of his initial body-weight of 137.5 pounds (62.4 kilograms). While both these values are somewhat

[1]Luciani, Das Hungern, Hamburg and Leipsic, 1890, plate II. See also this publication, fig. 3, p. 77.

less than the average loss found with L. and Succi, they are sufficiently close to imply that in all probability no measurable amounts of food were taken during these two uncontrolled fasts.

ANALYSIS OF LOSSES IN BODY-WEIGHT.

An analysis of the factors influencing the body-weight shows that there may be a retention of water in the body due to the drinking of more water than is excreted in the urine; a loss due to feces; a regular loss due to the oxidation of organized material, the carbon burning to carbon dioxide and the hydrogen to water; and a further loss of solids in the urine. The amount of organized material oxidized in the body will be influenced in large part by the muscular activity of the subject, and if the activity is constant, the loss due to oxidation will progress in a reasonably regular manner.

Considering the body as a living organism, therefore, we see that in a fasting experiment the intake consists of drinking water and oxygen from the air. The output consists of water-vapor and carbon dioxide given off from the lungs and skin and the urine and feces excreted. In this particular fast, however, the subject did not defecate during the experiment.

The water vaporized from the lungs and the skin and given off in the urine undoubtedly contains a large amount of preformed water which was taken with the water drunk each day. It also contains water which has been stored in the body and is given off as a result of the breaking down of the protein, *i. e.*, muscular tissue. There is likewise a small amount of water due to the combustion of the organic hydrogen of the body with the oxygen taken from the air. Without estimations of the carbon-dioxide excretion, there are at present no known means of satisfactorily computing these separate factors in the measurement of the water output. When it is possible to have the subject live the entire time inside the respiration chamber, as was done in the experiments at Wesleyan University,[1] the complete income and outgo may be determined, including the income of oxygen and water and the output of carbon dioxide, water-vapor, water in urine, solids in urine, and an analysis of the solids. An approximate apportionment may then be made of the water leaving the body as oxidized organic hydrogen and as preformed water in the body. This has already been done for the 7-day experiment reported in the earlier publication.[2] From the computed amounts of carbon dioxide excreted and the probable organic hydrogen oxidized, a similar apportionment of the water loss has been made for this experiment (see page 407 of this report).

Inasmuch as the body consists in large part of water—some 60 per cent or more—it will be seen that there may be an addition to or loss

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907.
[2]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 469.

from the storage of water in the body, as, for instance, 200 grams, without materially affecting the total percentage of water. It is easy to see, therefore, that the changes in weight noted from day to day with a fasting subject have only an indirect and passing influence.

INSENSIBLE PERSPIRATION.

In the long fasting experiment with L., the subject was not kept inside the respiration chamber for the entire time of the fast, so that the complete output of water-vapor was not determined. On the other hand, a study of the so-called "insensible perspiration," which has been of great interest ever since the days of Sanctorius, shows some facts of value.

The body loses in weight regularly as a result of the elimination of carbon dioxide and water-vapor. It loses weight spasmodically by the passing of urine and it gains in weight spasmodically by the drinking of water. By correcting for the amount of water taken and the weight of urine passed, the degree of insensible loss, or the "insensible perspiration," may be accurately calculated. This has been done in table 4, which gives for each day of the fast the loss of body-weight in grams, the weight of the urine passed, the weight of the drinking water taken, and the insensible perspiration. The excretion of urine was always less than the amount of the drinking water with one exception, that of April 29–30. The insensible perspiration is therefore readily obtained by finding the difference between the amount of water taken and the weight of urine excreted and adding it to the observed loss in body-weight.

A fact of special interest in this connection is that while the losses in body-weight fluctuate considerably, the losses as shown by the insensible perspiration are reasonably regular, the lowest being 371 grams on May 3–4; after the first 10 days, the highest value was 691 grams on April 25–26. Theoretically this insensible perspiration should give us a reasonable clue to the progress of the fast and should be an index of the loss of water and carbon dioxide. On the other hand, while the loss of preformed water is a real quantitative loss, the carbon dioxide and water of oxidation are not, as they are in large part made up of oxygen which is taken from the air.

In the later part of the fast it will be seen, from table 4, that this man had on the average an insensible perspiration of not far from 20 grams per hour. The insensible perspiration of the subjects in the fasts described in the earlier publication, particularly S. A. B., was inadvertently not reported. Subsequently, Benedict and Carpenter,[1] in discussing the metabolism of healthy men, computed the insensible perspiration of all of the fasting subjects. From their figures it will be seen that the fasting subject S. A. B., who spent 24 hours of each day

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, p. 114.

inside the respiration chamber, had an insensible perspiration of not far from 25 to 27 grams per hour. When it is considered that this represents the first 5 to 7 days of fasting, it will be seen that the results obtained for L. are quite in accordance with those secured with the earlier subject, in that they indicate a distinct tendency for the insensible perspiration to decrease as the fast progressed. It should be

TABLE 4.—*Insensible perspiration during fasting experiment with subject L.*

Date.	Day of fast.	Loss of body-weight. A	Urine. B	Drinking water. C	Insensible perspiration. Per 24 hours A+(C−B). D	Insensible perspiration. Per hour. E
1912.		*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
Apr. 14–15	1st	1040	674	720	1086	45
15–16	2d	920	482	750	1188	50
16–17	3d	890	581	750	1059	44
17–18	4th	760	731	750	779	32
18–19	5th	660	683	750	727	30
19–20	6th	480	624	750	606	25
20–21	7th	390	537	750	603	25
21–22	8th	420	601	750	569	24
22–23	9th	460	622	750	578	24
23–24	10th	500	578	750	672	28
24–25	11th	260	577	900	573	24
25–26	12th	320	529	900	691	29
26–27	13th	110	574	900	436	18
27–28	14th	300	660	900	540	23
28–29	15th	310	768	900	442	18
29–30	16th	580	902	900	578	24
Apr. 30–May 1	17th	470	861	900	509	21
May 1–2	18th	290	669	900	521	22
2–3	19th	390	740	900	550	23
3–4	20th	180	709	900	371	15
4–5	21st	440	717	900	623	26
5–6	22d	360	795	900	465	19
6–7	23d	170	566	900	504	21
7–8	24th	340	760	900	480	20
8–9	25th	290	722	900	468	19
9–10	26th	310	737	900	473	20
10–11	27th	320	663	900	557	23
11–12	28th	240	663	900	477	20
12–13	29th	360	706	900	554	23
13–14	30th	410	780	900	530	22
14–15	31st	300	575	900	625	26

borne in mind, however, in making any comparisons between the results obtained in these two fasting experiments, that while the subject S. A. B. remained in a respiration chamber the whole period of the fast and consequently had an approximately constant temperature environment and minimum muscular activity, the subject L. was not in a respiration chamber, but was for certain days partially naked for some time while being photographed, measured, or clinically examined, occasionally had a bath, and several times went out for a carriage

drive. His temperature environment and muscular activity were therefore more variable than those of the subject of the earlier fasting experiment.

An exact explanation of the variations in the insensible perspiration from day to day is difficult, particularly for those of May 3–4 and 4–5, when the lowest value of the fast was found on the day before a very much higher value was found. It is always possible that there may have been an error in the weighing, but on the other hand these weighings were very carefully made and recorded. Furthermore, an attempt to explain the variations on account of a difference in the activity is somewhat difficult, since the subject had a drive on May 3–4 and a bath and drive on May 4–5, and on other days when he was given a carriage ride the insensible perspiration was much greater than on May 3–4. It is obvious, therefore, that these figures should not be considered individually, but only as a general picture, this showing that the insensible perspiration had a tendency to decrease as the fast progressed. The increased value for May 14–15 may without doubt be explained by the fact that this being the last day of the fast, there was much greater excitement and muscular activity on the part of the subject. On this day he talked vigorously to a group of medical men for some 40 or 50 minutes; on this day, also, he was nude for a time while photographs were being taken and during a series of physical measurements. Considering the values generally, however, it will be seen that the insensible perspiration is a far more scientific basis for estimating the loss of body-substance during a fast than is the mere record of body-weight, which considers neither fluctuations in drinking water nor the volume of urine passed.

DRINKING WATER.

The intake of a fasting man is confined to water and oxygen of the air. Of these the water may be readily measured. Such measurements are of great importance in intelligently interpreting the losses in weight from day to day. Accordingly special care was taken to insure accurate records of the water consumed.

The selection of the kind and amount of drinking water for use in a long fast is by no means simple. On the one hand, there is the belief that distilled water is dangerous in that it washes out the salts from the body, while on the other there is the fact that in many fasts the subjects took either ordinary tap water or, as in Succi's fasts, various alkaline or spring waters containing large amounts of salts, sometimes of a distinctly purgative character. It has been believed by some that these mineral waters have an actual nutritive value due to the salts contained in them, if not to the organic matters. Furthermore, the supposition is reasonable that the salts interfere seriously with the mineral metabolism, and it is obviously impossible in a metabolism experiment to make an intelligent study of the output of sulphur, phosphorus, or

chlorine in the urine if at the same time the subject is taking a large amount of water containing sulphates, phosphates, or chlorides.

In the fasting experiments at Wesleyan University, one of the subjects, S. A. B., preferred distilled water.[1] Similarly Penny[2] records that he used only distilled water during his fast. Our subject, L., himself suggested that he be given distilled water during the fast, as otherwise it might be said that tap water was either not pure or contained mineral or organic matters which would contribute to his sustenance. Although an experiment in which the man used distilled water only was somewhat unusual, the desirability of being able to study the mineral metabolism without the conflicting factor of the ingestion of salts was, of course, apparent and arrangements were therefore made for supplying L. with distilled water throughout the fast.

Dr. E. P. Cathcart was at this time a Research Associate of the Nutrition Laboratory and advised that L. be given a constant amount of drinking water each day, since in his observations on Beauté he had experienced considerable difficulty with the volumes of the urine. Our subject was first given 1,000 c.c. of distilled water, but was able to take but 720 c.c. on the first day. L. then suggested that he be given only 750 c.c. This amount was continued for a number of days, when it was increased to 900 c.c., at which volume it continued throughout the remaining days of the fast.

The amount of water taken each day by the subject is given in table 4. Since the body excretes so large an amount of water, it is perhaps somewhat unfortunate that the volume taken by the subject was not constant for the whole period of the fast, although it is much more nearly uniform than in any long fast heretofore reported. In any discussion of the body-weight or the volume of urine, it is obviously necessary to consider these fluctuations in the intake of water.

The subject was very inconsistent in his comments regarding the water. On some days he said it was very good, but on other days considered it to be very bad, although exactly the same amount was given him and from the same glass carboy. On some days, also, he found the amount given him was not enough and again not infrequently complained that he was given too much water. He recognized the importance, however, of maintaining the volume of urine so that a large number of analyses could be made.

The daily allotment of distilled water was supplied to the subject in a bottle and from this he poured out the amount desired. Early in the fast he found that it was desirable to drink as large a portion of water as possible during the first part of the day, so that it would not be necessary for him to urinate during the night. The records show that he rarely urinated during the night. Furthermore, as in the later part of the

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, pp. 136 and 140.
[2]Penny, British Med. Journal, 1909, p. 1414.

fast he divided the urine into day and night periods, it provided a particularly satisfactory method for studying the constituents of the urine separately for these periods. Usually the last of the water was taken a short time before the subject entered the bed calorimeter for the night experiment.

At the end of the first 10 days of the fast, during which L. had taken but 750 c.c. of water daily, the attending physician, Dr. H. W. Goodall, expressed the opinion that there was a distinct physiological need of water in the body. The lips of the subject were parched, his skin was dry, and dandruff appeared. At Dr. Goodall's suggestion, L. was prevailed upon to increase the amount of drinking water to 900 c.c. daily. Two days later he reported to Dr. Goodall that for the first time he felt thirst. Unfortunately some of the statements of the subject were so inconsistent at this time that it is difficult to say whether or not there was a physiological need for water which was not felt by the subject but which was observed by the physician.

Aside from the objective indications noted by Dr. Goodall, the need for water in the body may be inferred, though not scientifically proved, by the figures given in table 4, the difference between the water taken and the urine excreted being considerably increased when the water intake was changed from 750 c.c. to 900 c.c. The subject had previously excreted in the urine about 600 c.c. of water daily, but when the intake of water was increased, the amount given off in the urine was actually decreased for several days, so that an average of over 340 c.c. of water was retained per day for three days. This increase in the difference between the water taken and urine excreted would imply a distinct physiological need, since in the earlier experiments at Wesleyan University, in which the subjects fasted for a shorter period and the intake of water fluctuated widely, the variations in the amount of the urine followed very closely the variations in the amount of water ingested by the subject.

Finally, it is significant that at no time was there any indication of a toxic effect in using distilled water, and we are able to sustain the contention of Winckler[1] that distilled water is without deleterious effect.

[1]Winckler, Zeitschr. f. diat. u. physikal. Therapie, 1905, 8, p. 567.

BODY-TEMPERATURE.

The profound alterations in metabolism in the body of a fasting man would lead one to expect some disturbance between thermogenesis and thermolysis. Body-temperature, which is the index of the resultant of these two factors, may obviously be affected by the disturbance of either. If there is a decrease in thermogenesis with no change in the thermolysis, there will be a fall in body-temperature. Conversely, if there is an increase in thermolysis with constancy of thermogenesis, there will again be a fall in temperature.

In this laboratory body-temperature measurements have a dual significance: first, the value *per se* of the actual fluctuation, which indicates a disturbance in the relationship between thermolysis and thermogenesis, and second, the importance of knowing body-temperature changes for the accurate computation of the heat production in the body. To determine the heat production it is not sufficient simply to measure the heat radiated from the body and to add to this value the heat of vaporization of water, for if in a given experimental period the body-temperature has decreased, there has been a loss of heat from the body unaccompanied by a production; hence the heat production is measured only after correcting for the body-temperature changes. In the series of body-temperature measurements in the short fasts at Wesleyan University, the average body-temperature did not alter noticeably, although there was distinct evidence of a flattening out of the curve showing the daily rhythm. In the prolonged fasting experiment with our subject L., we attempted to measure with the greatest degree of refinement all the factors. It seemed important, therefore, that frequent and careful records of the body-temperature should be made in connection with this fasting observation.

The subject of body-temperature has been given special attention in this laboratory for a considerable period, and a year previous to this fasting experiment an extensive study of the fluctuations of the temperature in the various parts of the human body was reported.[1] As a result of this research, it became evident that the only suitable place for measuring body-temperature is deep in the body trunk, preferably in the rectum. The identical apparatus used in the study referred to was available for this fasting experiment and consequently body-temperature measurements were secured as frequently as possible. A detailed description of this apparatus and the tests made with it were published in the report cited. Briefly, the apparatus consists of a thermal element which is inserted about 7 cm. in the rectum, this thermal element being connected with another thermal junction in a constant-temperature bath. By means of this apparatus, it is possible

[1]Benedict and Slack, Carnegie Inst. Wash. Pub. No. 155, 1911.

to determine the rectal temperature of a subject within 0.01°C., and records can be made as frequently as desired.

Records of the rectal temperature were obtained nearly every night while the subject was in the calorimeter chamber, the junction being inserted in the rectum of the subject, connections made with the binding posts inside the chamber, and observations taken on an average of every 15 minutes throughout the night. On some nights records were taken every 5 or 6 minutes. Observations were also made at various times during the day and on at least two days continuous records were secured for nearly the whole day-period. The apparatus was frequently controlled by comparison with a standard thermometer, so we believe that these observations represent the absolute temperature changes of this individual.

As in most of the measurements taken during the fast, the subject cooperated heartily in these body-temperature observations. After the first night, and, in fact, after the thermometer had been inserted a few moments, he experienced no particular difficulty and expressed himself as being very much pleased that this routine gave him no discomfort. It is clear that the use of the thermometer did not interfere in the slightest with his sleeping. The observations were therefore made under normal conditions, so far as it was possible to control them.

The body-temperature measurements made in this fasting experiment may be considered in two ways: first, as to the alteration in the regular rhythm of the temperature as the fast progressed, and second, as to the effect of the fast upon the average of the temperature measurements.

CHANGES IN TEMPERATURE RHYTHM.

In order to study the first of these problems, namely, the changes in the temperature rhythm, curves have been plotted giving the temperature values for the period beginning about 8 p.m. and ending about 10 a. m. the following day. During this time the subject was in the calorimeter chamber from 8 p. m. until about 8 a. m., and then, without leaving the bed, he was withdrawn from the apparatus and was for the next two hours the subject of the morning respiration experiments. Accordingly, he was lying on the same bed in the same position for the entire time, the only change being that in the last two hours he was in the calorimeter room instead of inside the calorimeter chamber. Since the temperature of the calorimeter laboratory was essentially that of the respiration chamber, there was practically no alteration in the temperature environment throughout the whole period covered by the observations shown by the curve.

It is, furthermore, of value to note that this period includes what is normally found to be the maximum diurnal change, for with normal individuals it has been shown that the lowest temperatures are found about 3 a. m. and the highest about 5 p. m. From 5 p. m. until

about 11 p. m., or until bedtime, the temperature usually remains approximately constant. The temperature, as a rule, falls rather rapidly after one goes to bed, reaching the minimum about 2 or 3 a. m. With the fasting subject, the maximum temperature undoubtedly was reached prior to his entering the chamber at 8 p. m., as he usually lay on the couch for an hour or more previous to that time. The body-temperature was unquestionably falling continuously during this preliminary period, so that the range for the night would be somewhat less than the actual daily range.

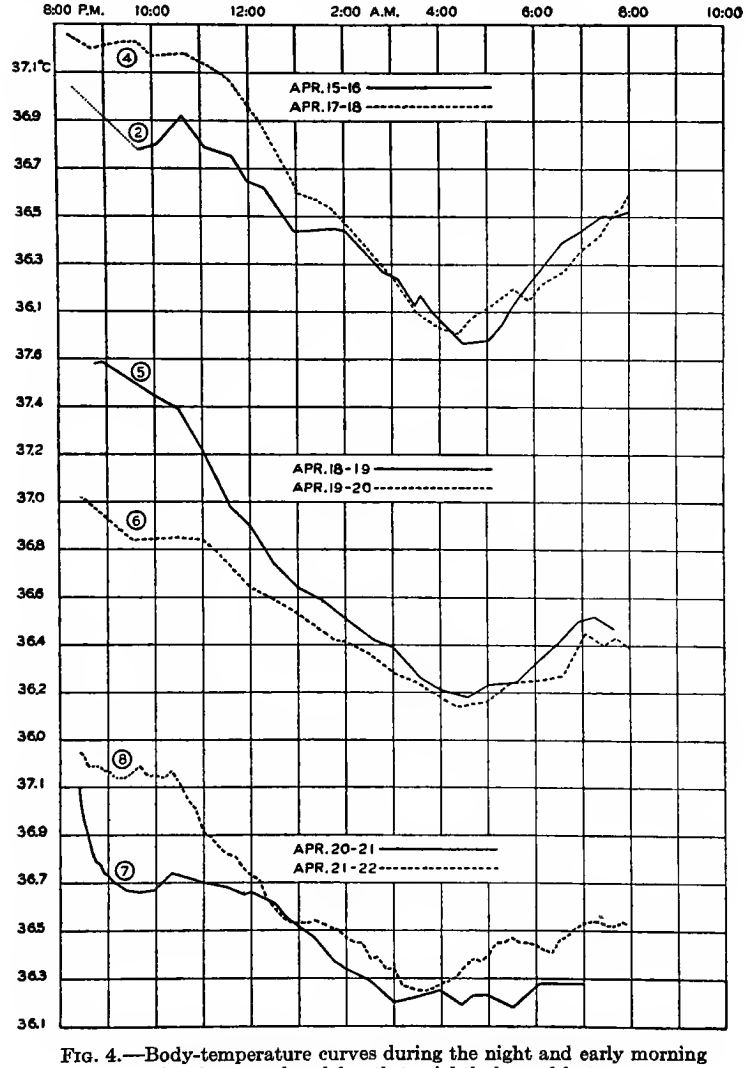


FIG. 4.—Body-temperature curves during the night and early morning for the second and fourth to eighth days of fast.

The temperature curves for the period from 8 p. m. to about 10 a. m. for every day of the experiment, with but three exceptions, are given in figures 4 to 8. In order to save space, it has been necessary to plot the curves in pairs, but the observations are of such interest that it appears unwise to plot them in larger groups. The day of the fast is indicated by a number in a circle on each curve. It can be seen that the general trend of the curves remains essentially the same throughout the entire fast. There is a noticeable fall in the evening, the minimum being reached not far from 3 or 4 a. m. This is followed almost invariably by a distinct rise, which continues until the end of the record.

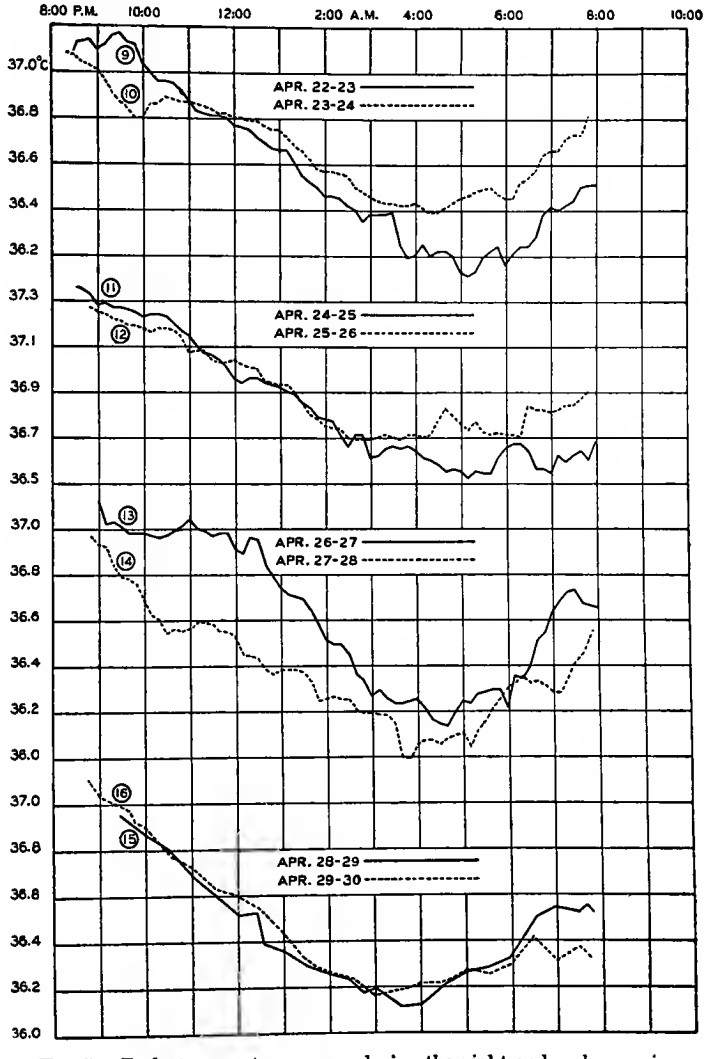


FIG. 5.—Body-temperature curves during the night and early morning for the ninth to the sixteenth days of fast.

OBSERVATIONS OF THE BODY-TEMPERATURE IN THE NIGHT PERIOD.

AVERAGE BODY-TEMPERATURE.

The greatest interest, at least to the clinician, lies not in the course of the temperature curve throughout the night, but in the average temperature values as the fast progresses. These are recorded in table 5 (page 95) for nearly every night of the fasting experiment, only the time that the subject was inside the bed calorimeter being included in the values. These averages were taken directly from plotted curves and, except in the values for the tenth to the fourteenth nights of the fast.

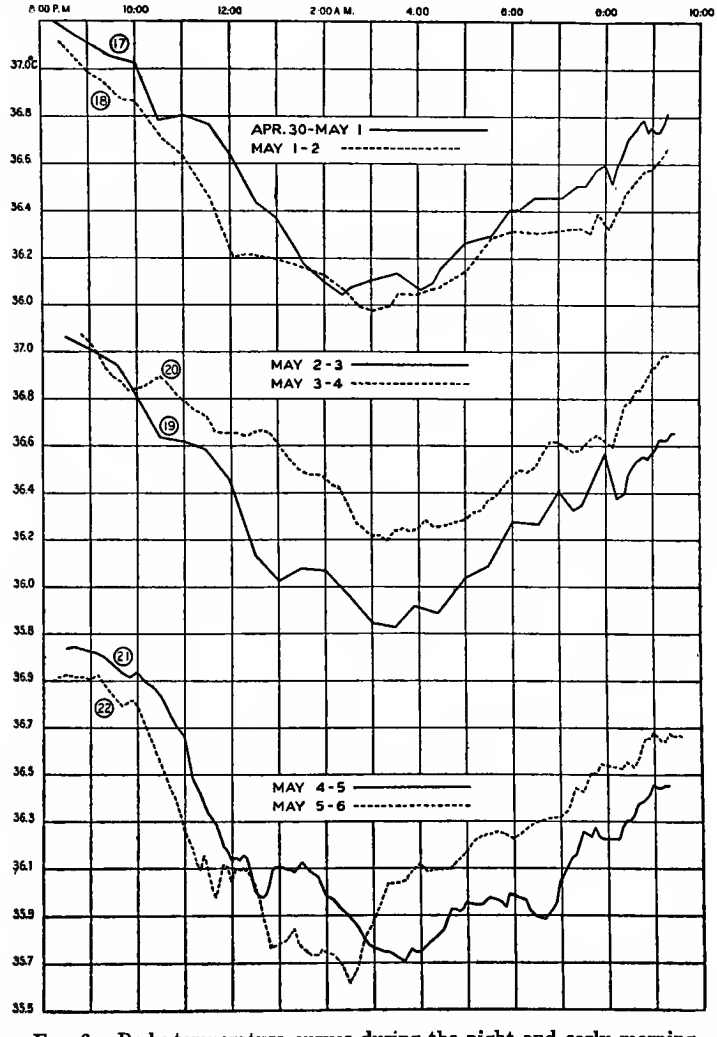


FIG. 6.—Body-temperature curves during the night and early morning for the seventeenth to twenty-second days of fast.

show a general tendency for the temperature to remain reasonably constant up to the seventeenth night of fasting. The temperature then fluctuated, falling as low as 35.88° C. on the twenty-fourth night of fasting and rising as high as 36.37° C. on the twenty-eighth night of the fast. The maximum average value for the body-temperature observed in any night during the fast was 36.85° C. on the twelfth night and the minimum value was 35.88° C. on the twenty-fourth night. On the last night of the fast, the average body-temperature was 36.14° C.

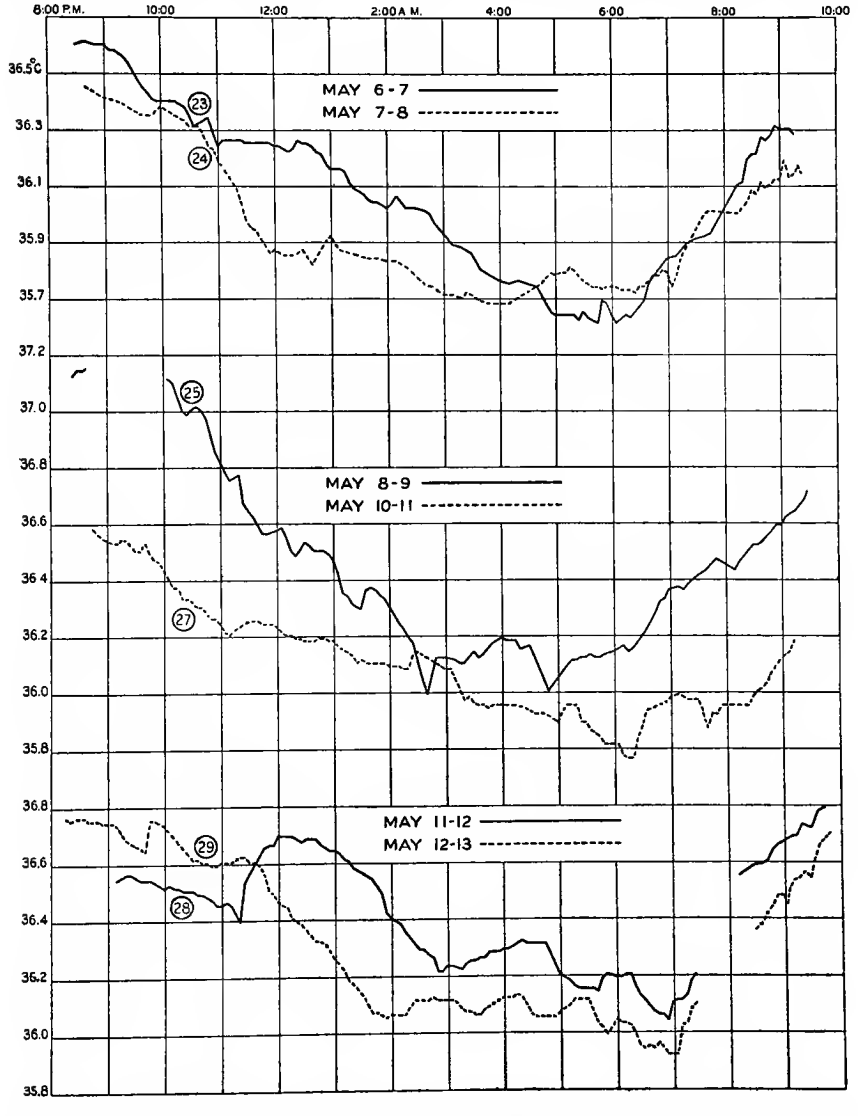


FIG. 7.—Body-temperature curves during the night and early morning for twenty-third to twenty-ninth days of fast.

With the resumption of food the average temperature increased on May 16–17 to 36.79° C. and on May 17–18 to 37.53° C.

RANGE IN BODY-TEMPERATURE.

The maximum and minimum temperatures and the range in the temperature for each night are likewise recorded in table 5. The maximum temperature observed on any fasting night was 37.45° C. on the fifth night; the minimum temperature was 35.61° C. on the twenty-second and twenty-third nights. The difference between the minimum and maximum values, or the range in temperature, is also recorded in table 5. The average range was not far from 0.90° C. The maximum range, 1.27° C., was observed on the fifth night of fasting; the minimum

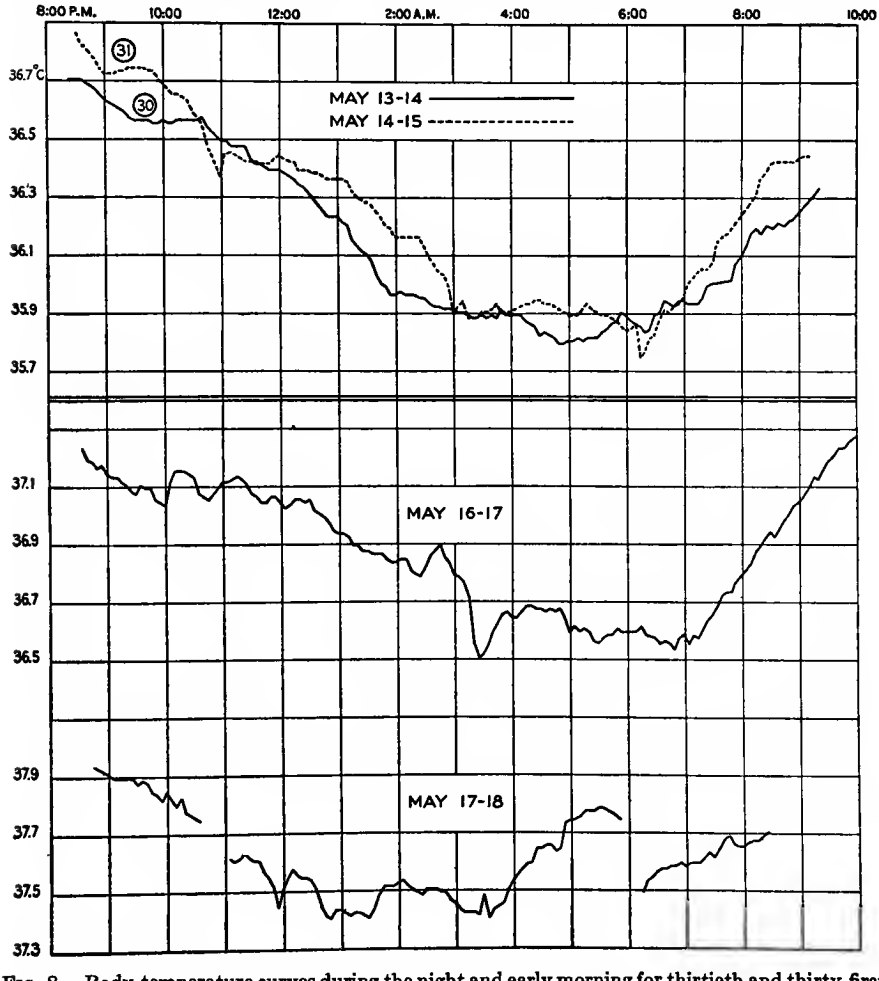


FIG. 8.—Body-temperature curves during the night and early morning for thirtieth and thirty-first days of fast and second and third days with food.

range was 0.50° C. on the twelfth night of the fast. It is important to note, however, that the variations in the range have not even the semblance of regularity.

OBSERVATIONS OF THE BODY-TEMPERATURE IN THE DAY PERIOD.

On two days (May 7–8 and May 8–9) the body-temperature was measured almost continuously throughout the entire 24 hours. Curves showing the fluctuations in body-temperature on these days are given

TABLE 5.—*Body-temperature (rectal) of subject L. during experiments in the bed calorimeter at night.*

Date.	Day of fast.[1]	Max.	Min.	Range.	Average.	Observation at 7 a.m.
1912.		° C.	° C.	° C.	° C.	° C.
Apr. 15–16	2d	36.92	35.97	0.95	36.41	36.44
17–18	4th	37.23	36.01	1.22	36.65	36.36
18–19	5th	37.45	36.18	1.27	36.58	36.50
19–20	6th	36.85	36.14	.71	36.44	36.42
20–21	7th	36.74	36.18	.56	36.42	36.28
21–22	8th	37.17	36.25	.92	36.55	36.53
22–23	9th	37.12	36.11	1.01	36.50	36.41
23–24	10th	36.96	36.39	.57	36.64	36.66
24–25	11th	37.28	36.62	.76	36.80	36.54
25–26	12th	37.19	36.69	.60	36.86	36.81
26–27	13th	37.04	36.13	.91	36.62	36.63
27–28	14th	36.60	35.99	.61	36.30	36.28
28–29	15th	36.95	36.11	.84	36.43	36.54
29–30	16th	36.92	36.16	.76	36.40	36.31
Apr. 30–May 1	17th	37.06	36.04	1.01	36.42	36.45
May 1–2	18th	36.95	35.97	.98	36.30	36.31
2–3	19th	36.86	35.82	1.04	36.21	36.40
3–4	20th	36.88	36.19	.69	36.51	36.61
4–5	21st	36.96	36.70	1.26	36.12	36.04
5–6	22d	36.67	35.61	1.06	36.10	36.31
6–7	23d	36.48	35.61	.87	35.98	35.84
7–8	24th	36.38	35.68	.70	36.88	35.78
8–9	25th	37.00	35.99	1.01	36.31	36.36
10–11	27th	36.27	35.76	.61	36.03	35.98
11–12	28th	36.69	36.04	.65	36.37	36.10
12–13	29th	36.75	35.92	.83	36.23	36.92
13–14	30th	36.57	35.79	.78	36.06	35.94
14–15	31st	36.74	35.74	1.00	36.14	35.96
16–17		37.15	36.50	.65	36.79	36.58
17–18[2]		37.78	37.40	.38	37.53	[3]37.58

[1]For the duration of the period during which these observations were made, see table 44.
[2]The maximum temperature on this night was observed near the end of the calorimeter period.
[3]This observation was obtained during the morning respiration experiment, the subject lying on the couch after leaving the calorimeter.

in figure 9. These curves, which were obtained on the twenty-fourth and twenty-fifth days of the fasting experiment, show that even late in the fast there was a very large diurnal variation.

It has been stated that the range in temperature during the night was not a criterion of the probable total range throughout the 24-hour

day, for before the night observation began the subject had been in a condition of rest for one or more hours. On these two days the maximum temperature observations occurred during the daytime, as, for instance, on May 7–8, when the maximum temperature observed was 37.10° C. at about 5 p. m., the normal hour of the day. The minimum record was 35.68° C. at 4 a. m., the entire range being 1.42° C., a value exceeding any range given in table 5. Similarly on May 8–9, the highest temperature recorded was in the daytime at about $12^h\ 15^m$ p. m., when a temperature of 37.51° C. was recorded. The minimum value was 35.99° C., at $2^h\ 40^m$ a. m. Thus the range was 1.52° C., exceeding even that of the preceding day. These curves give a general picture of what was probably the average daily course of the body-temperature

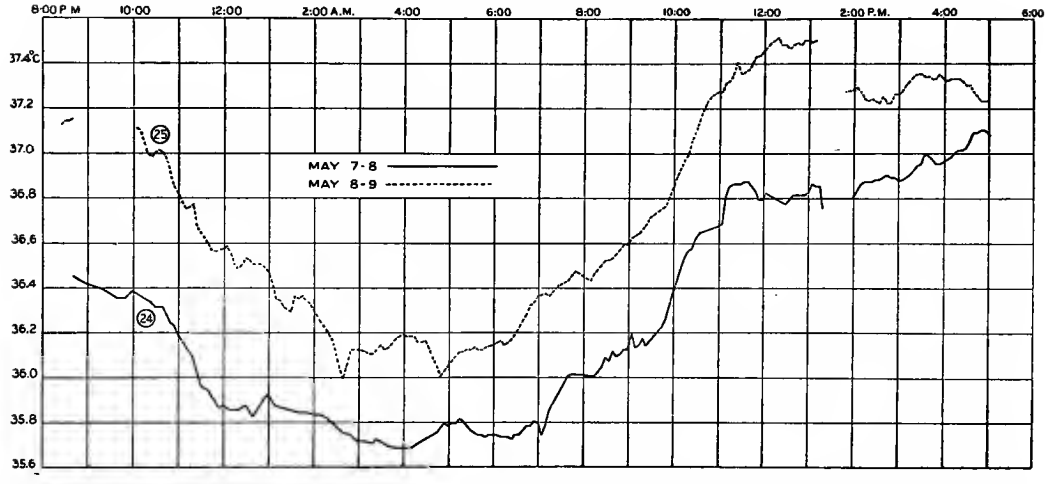


FIG. 9.—Body-temperature curves for approximately 24 hours on twenty-fourth and twenty-fifth days of fast.

of this subject throughout the 31 days of fasting. Here, again, there is a distinct tendency for the maximum temperature to appear in the late afternoon and the minimum temperature in the early morning, this not being affected by many days of fasting.

On three other days, body-temperature records were obtained for a part of the morning. On May 1 and 4, observations were made during respiration experiments in which L. was sitting up and writing. (See plate 1, fig. B.) These values are given in figure 10. This experiment followed the regular morning respiration experiment, in which the subject lay upon a couch; the observations recorded for the lying position are also given in figure 10 for comparison. Of particular interest is the fact that the change in position from lying to sitting did not greatly alter the rate of the morning rise in temperature.

On May 15, when the subject first began to eat, the observations commenced shortly after the end of the regular respiration experiment

and continued until noon. During this time the subject was sitting up and eating. The curve given in figure 11 for both the respiration experiment and the eating period shows that when the subject was sitting and eating the ascent is somewhat more noticeable than in the lying period, but it is evident that even eating after a 31-day fast did not materially disturb the course of the rectal temperature curve.

CONSTANCY IN BODY-TEMPERATURE AT A GIVEN HOUR.

Since at 7 a. m. the subject had been living under constant conditions of quiet and rest inside the chamber for 8 or 10 hours, a comparison may be made of the values for the body-temperature obtained at this time from day to day. This comparison is the more important since

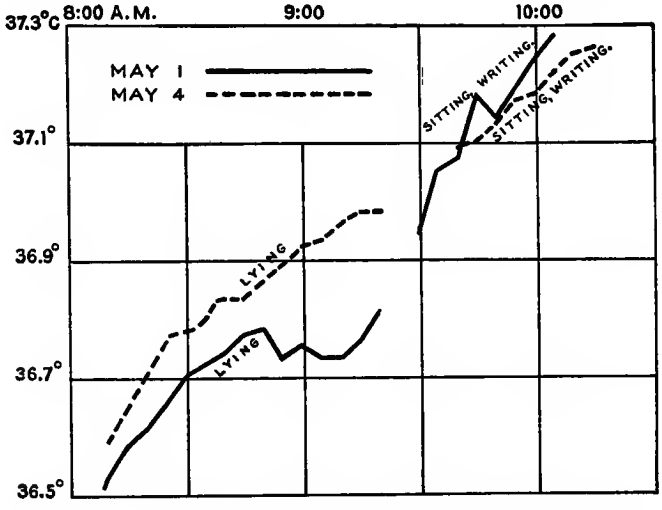


FIG. 10.—Body-temperature curves showing change from lying to sitting position.

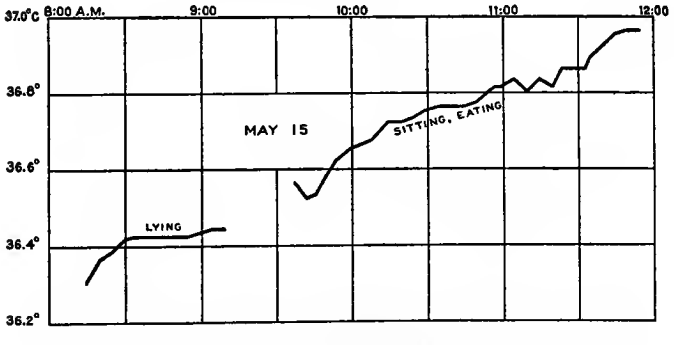


FIG. 11.—Body-temperature curve showing change from lying to sitting position.

in many fasts the body-temperature measurements are made but once each day and usually at a given hour. Accordingly, in table 5 the temperature records obtained at or near 7 a. m. have been given for each day. In general, the variations in the temperature at 7 a. m. are not markedly different from the variations in the average temperature throughout the night, since the maximum and minimum records for this time were found on the same days as the maximum and minimum average temperatures. The maximum value found at 7 a. m. was 36.81° C., at the end of the twelfth night of fasting, and the minimum value 35.78° C., at the end of the twenty-fourth night of fasting. No uniformity in the values is apparent.

With the fluctuations in the body-temperature varying as they do it will be seen that the difficulties in securing an average temperature throughout the fasting period by means of one or two observations during the day have been overlooked. Only by securing average values throughout the entire night or throughout several hours at approximately the same time each day can a true picture of the average temperature change of the body as affected by inanition be secured.

The well-known influence of muscular activity on body-temperature makes it the more regrettable that certain experiments with muscular activity could not have been carried out with this subject, as the effect of a moderate amount of muscular exercise upon the temperature regulation as the fast progressed would have great theoretical interest. This is one of the problems that should certainly be studied in any subsequent fasting experiment.

The observations of body-temperature on other fasting individuals have frequently been made without reference to the preceding muscular activity or the general condition of the subject. Obviously those made in the morning, just before the subject rises, have by far the greatest value. It is a characteristic of practically all the fasts heretofore reported—in which the temperature observations have been made for the most part in the axilla or in the mouth (both localities unsuited for physiological experiments)—that there has not been sufficient disturbance in the temperature regulation to be recorded by this method of thermometry.

PULSE-RATE.

In practically all of the fasting experiments with which we are familiar, the method of taking the pulse-rate from the radial artery has been used. In the fasting experiments made at Wesleyan University, in which the subject remained in the calorimeter during the whole period, it was at first necessary to rely upon the subject's own observations of the radial pulse. This method was by no means ideal and, in a later series of 2-day fasting experiments with seven individuals, the method was improved upon, in that a small tube-pneumograph was placed about the chest. The pulse-beats were thus superimposed upon the respiration movements of the tambour and could be counted by an observer outside of the chamber.

The striking relationship between pulse-rate and metabolism, which has been regularly noted in this laboratory for many years, not only with men but with animals and more recently with infants, led us to be especially interested in the pulse-rate of our fasting subject. For a study of the pulse-rate during the fasting experiments, it was necessary to select a method by which continuous records could be made, as the pulse-rate gives a reasonably accurate index of the metabolism at the time the pulse record is made. The method of recording the pulse-rate from the radial artery, either by an observer or by the subject himself, has distinct disadvantages in that the knowledge that the observation is being made has a psychical influence which is undesirable. Continuous records, therefore, could not be obtained by this method. Furthermore, while the pneumograph method may properly be used in a short experiment, its use in a long-continued experiment is objectionable. The wearing of the pneumograph for a considerable period of time may cause the subject much discomfort, as the traction becomes wearisome, and if he changes his position during the experiment inside the calorimeter the pneumograph may possibly press into the flesh and be somewhat painful. The transmission tube may also become twisted and thus interrupt the record.

It was hoped that this continuous record of the pulse-rate could be obtained by photographic registration with the string galvanometer, but although Professor W. B. Cannon kindly loaned us the string galvanometer belonging to the Harvard Medical School, it was impossible to install and test it suitably in time for its use in this experiment. In our previous experimenting we had found it advantageous to fasten the bell of a Bowles stethoscope over the apex beat of the heart and by using long transmission tubes very satisfactory counts of the pulse-rate were obtained. Accordingly, since records could not be made by photographic registration, the stethoscope was used for nearly all of the observations in this fasting experiment. The stethoscope is much less

disturbing to the subject than feeling of the radial pulse, but a few additional records were obtained by the latter method. In the later days of the fast, when the apex beat of the heart became fainter, it was occasionally necessary for the observer in the respiration experiments to note the pulsations of the carotid artery.

The pulse-rate records may be classed in two groups. The first includes a large number of perfectly comparable observations: those made throughout the night, while the subject was inside the bed calorimeter, and those during the 1½ or 2 hours of the morning respiration experiment. Usually the period of continuous observation extended from 8 p. m. to $9^h\ 30^m$ or 10 a. m.; during this time the subject was lying quietly upon a couch. These records were made regularly every day of the fast.

While the subject was in the bed calorimeter, the records were made by the regular chemical assistant as often as possible, the frequency of the observations obviously depending somewhat upon his other duties. Occasionally when the subject moved inside the calorimeter, so as to slightly displace the bell of the stethoscope, the pulse beats could not be heard and there would consequently be a break in the records until the subject again changed his position so as to bring the bell to its former location. During the morning respiration experiment a special observer was detailed to count the pulse-rate continuously throughout the whole period. (See plate 2, figure C, page 19).

The second group of observations consists of those taken at various times throughout the day, a part of which were continuous, while others were individual records. This group includes the observations in the miscellaneous respiration experiments, such as those made in the evening before the subject entered the bed calorimeter, while the subject was writing, or when he was breathing an oxygen-rich atmosphere. During the latter part of the fast, the pulse-rate was also recorded twice when the daily record of the blood pressure was taken, and occasionally when other special tests were made. At times the subject wore the stethoscope throughout the whole day, so that the observations were more or less continuous for the 24 hours. On the days when the continuous observations were made, the subject was followed by an assistant who kept out of sight but made the records regularly and also noted the changes in body-position. These records were frequently verified by a second observer.

RECORDS OF PULSE-RATE OBTAINED IN EARLIER FASTING EXPERIMENTS.

Before giving the records of the pulse-rate obtained in the fasting experiment with L., it will be of interest to cite those secured in fasting experiments made by other investigators. In discussing such observations, two essentially different comparisons can be made, first, the influence of a prolonged fast upon the pulse-rate determined under any given conditions, and second, the variations in pulse-rate incidental to the changes in position or mental activity. Usually in fasting experi-

ments observers have contented themselves with taking the morning pulse-rate and occasionally the evening pulse-rate. No particular emphasis has been placed upon these individual observations, aside from the general fact that the pulse may have altered as the fast progressed. Not recognizing the great significance of the pulse-rate in relation to the metabolism, experimenters have not ordinarily taken especial precautions (as did Luciani) to keep the subject lying quietly while the pulse-rate was being observed and, indeed, for some time previous to the observation. This probably explains difficulties found in comparing the records, in that some observers note a continually decreasing pulse-rate during the fast, while others find marked irregularities. As would be expected, the more recent observations take into account the factors influencing the pulse-rate and the records are thus more trustworthy.

Of the pulse records obtained in Tanner's fast, we have been able to find only those given in the British Medical Journal.[1] On the thirty-seventh day of this fast, the pulse, respiration, and temperature are reported as having been "normal." On the twenty-fifth day the pulse-rate is given as 75, the respiration as 15, and the temperature of the mouth as 98.4° F. (36.89° C.). On the thirtieth day the pulse-rate was reported as 84 and slightly more regular, the temperature as 98.8° F. (37.11° C.), and the respiration as 14, with the general statement that he was weaker than on any previous day. "On the twenty-ninth day, two of the experts attending him reported that there was no material alteration in the vascular pressure indicated by the heart's impulse, while its volume was scarcely less than in health."

Paton and Stockman[2] report that the pulse-rate of their subject averaged between 50 and 60 and the respiration usually between 23 and 30, but no continuous records of the pulse-rate are given.

The most extensive series of continuous observations of the pulse-rate of a fasting subject is that reported by Hoover and Sollmann.[3] In this 5-day fast, the pulse was counted and recorded once every hour by relays of watchers. The initial record of the pulse-rate was 75, the lowest value of 37 being recorded on the last day, thus showing a distinct tendency for the pulse-rate to decrease as the fast progressed. Unfortunately the fast continued for only 5 days and, in the opinion of the authors, the pulse records are vitiated by the fact that they were obtained with a hypnotic subject and that the pulse-rate was purposely lowered by suggestion.

In reporting a fast carried out by Succi in New York in December 1890, and said to have continued for 45 days, a newspaper states[4] that on the last day of the fast Succi's pulse-rate was 62. Unfortunately no scientific record of this fast was ever published.

[1] British Med. Journ., 1880, 2, p. 171.
[2] Paton and Stockman, Proc. Roy. Soc., Edinburgh, 1888–1889, 16, p. 121.
[3] Hoover and Sollmann, Journ. Exp. Med., 1897, 2, p. 403.
[4] N. Y. Daily Tribune, December 21, 1890.

In a fast carried out by Succi in London in 1890, which continued 40 days, the pulse-rates, taken every day at noon,[1] varied from 82 on the second day of the fast to 52 on the thirty-fifth day. The degree of irregularity noted in all conditions of the fast, however, shows that proper attention had not been paid to secure uniform quiet before the observations were made. The respirations varied from 16 on the thirty-first day of the fast to 28 on the sixth day of the fast. Here again the irregularity noted on all days implies variations in muscular activity prior to the observations, no general trend of the respiration rate being apparent.

In the 10-day fasting experiment with Cetti,[2] the pulse-rate ranged from 68 on the morning of the fourth day to 92 in the afternoon of the seventh day. The high pulse-rate was accompanied by abdominal pains. In certain of the respiration experiments carried out with Cetti, the pulse-rate was likewise recorded. In one instance it was noted that the pulse-rate changed from 88 while the subject was lying down to 120 while he was walking about the room. In another experiment the pulse-rate changed from 86 while he was lying down to 98 when he was sitting, smoking, and talking. The great increase in the heart action of this subject was commented on at some length by these authors.

In an experiment with Breithaupt, continuing for 6 days, the same authors record a minimum pulse-rate of 47 on the last day of the fast and a maximum rate of 66 on the morning of the second day. Taking advantage of the fact that their subject performed muscular work on the ergostat, the authors made some interesting notes upon the increase in the heart-beat with a definite amount of work and the return of the pulse-rate to normal after the work ceased. In their general conclusions they maintained that with Cetti, who was of an excitable temperament, the pulse-rate in the resting condition was not noticeably changed by fasting, but that it slowly decreased with Breithaupt, who was quiet and phlegmatic. They also emphasize the fact that during the fast there was a distinct tendency to a considerable increase in the irritability of the heart, slight muscular activity producing a great increase in the pulse-rate.

Luciani contends that, during his experiment with Succi, the pulse-rate remained strictly inside the physiological limits, rising to 70 but twice and only occasionally falling below 50. He also points out that the pulse-rate, as well as the temperature and the respiration, were always measured during complete muscular rest, as the subject was lying in bed. An interesting observation on the irritability of the heart, as indicated by the rise in the pulse-rate after exercise, was likewise made by Luciani, who was fortunate in having a fasting subject who freely indulged in muscular activity.

[1] British Medical Journal, 1890, pp. 764, 819, 876, 935, 996, 1056, and 1444.

[2] Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol. u. f. klin. Med., 1893, **131**, Supp., p. 1.

The pulse-rates were also recorded in a long fast made by Penny.[1] This fast was less strictly controlled than the previous fasts cited, but Penny states that his observations of the pulse-rate were verified by another doctor. The morning observations were made about 9 o'clock before he rose from his bed; the evening pulse-rate was taken about the time of retiring, *i. e.*, 10 or 11 o'clock. The records for the morning ranged from 59 on the second day of the fast to 39 on the thirteenth, fourteenth, fifteenth, and eighteenth days of the fast. The evening records ranged from 80 on the last day to 44 on the eleventh, fifteenth, and sixteenth days of the fast.

Far less confidence can be placed in the observations reported for Gayer, who was said to have carried out a 30-day fast in New York in 1910. My only justification for calling attention to these observations in the report of this fast is the personal assurance of Dr. Ira S. Wile, of New York, who, while not vouching for the authenticity of the fast, is inclined to believe that the records are for the most part trustworthy. These show a pulse-rate ranging from 54 to 80, but, as the writer points out, the maximum observation was taken after the subject had come in from a 2-mile walk and on the very next day a pulse-rate of 61 was noted when the subject spent the morning lying down.

Cathcart[2] recorded both the morning and evening pulse-rates of his subject, Beauté. Charteris[3] also recorded the pulse-rates on this individual, but obviously at a slightly different time of day, as his records do not agree with those of Cathcart. Nevertheless both authors draw the conclusion that there was a general tendency for the pulse-rate to fall as the fast progressed. Charteris furthermore points out that the subject was well aware of this fact from his previous experience, as he was a professional faster. Cathcart's morning observations ranged from 70 on the seventh day of the fast to 58 on the twelfth and fourteenth days of the fast. The highest observation secured in the evening was 71 on the second day, and the lowest was 57 on the tenth day of fasting. The records obtained by Charteris show a range from 68 on the second day of fasting to 58 on the twelfth day of the fast.

RECORDS OF PULSE-RATE OBTAINED IN THE EXPERIMENT WITH SUBJECT L.

The number of observations obtained with L. was sufficient to justify their presentation in the form of 24-hour curves, as shown in figures 12 to 18. In these curves the day begins with 8 p. m., when the subject entered the respiration calorimeter, ending 24 hours later. Continuous records were secured for every night experiment and frequent records were made during the day. The values are perfectly comparable for each day between 8 p. m. and 10 a. m. and also for the most part throughout the rest of the day, as the daily routine of the subject was

[1] Penny, British Med. Journ., 1909, p. 1414.
[2] Cathcart, Biochem., Zeitschr., 1907, **6**, p. 109.
[3] Charteris, Lancet, 1907, **173**, p. 685.

more or less regular. The pulse records which were obtained in the evening respiration experiments may logically be attached to the records for the bed-calorimeter experiments as preliminary periods, but the fact that the evening experiments were made only in the latter part of the fast complicated their presentation in this manner. As a matter of fact, the record of the pulse-rate from the beginning of the evening respiration experiment, *i. e.*, about 7 p. m., until the close of

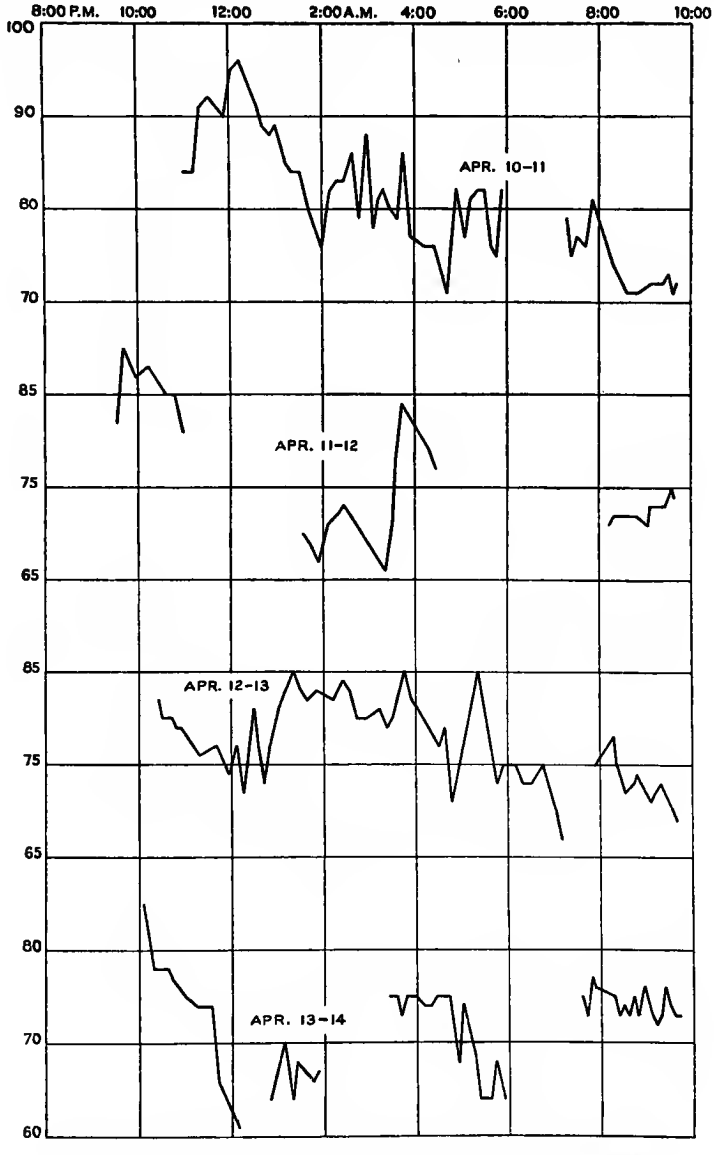


FIG. 12.—Pulse-rate chart of subject L. for days preceding fast.

the respiration experiment the next morning at $9^h\ 30^m$ or 10 a. m., was continuous, as the subject did not rise from his couch during that period. He urinated lying on the side. Since the conditions of activity were essentially uniform from the time the subject entered the bed calorimeter at about 8 p. m. until the end of the morning respiration experiment at $9^h\ 30^m$ or 10 a. m., the records of the pulse-rate taken during this period on every day of the fast are more comparable. It is therefore

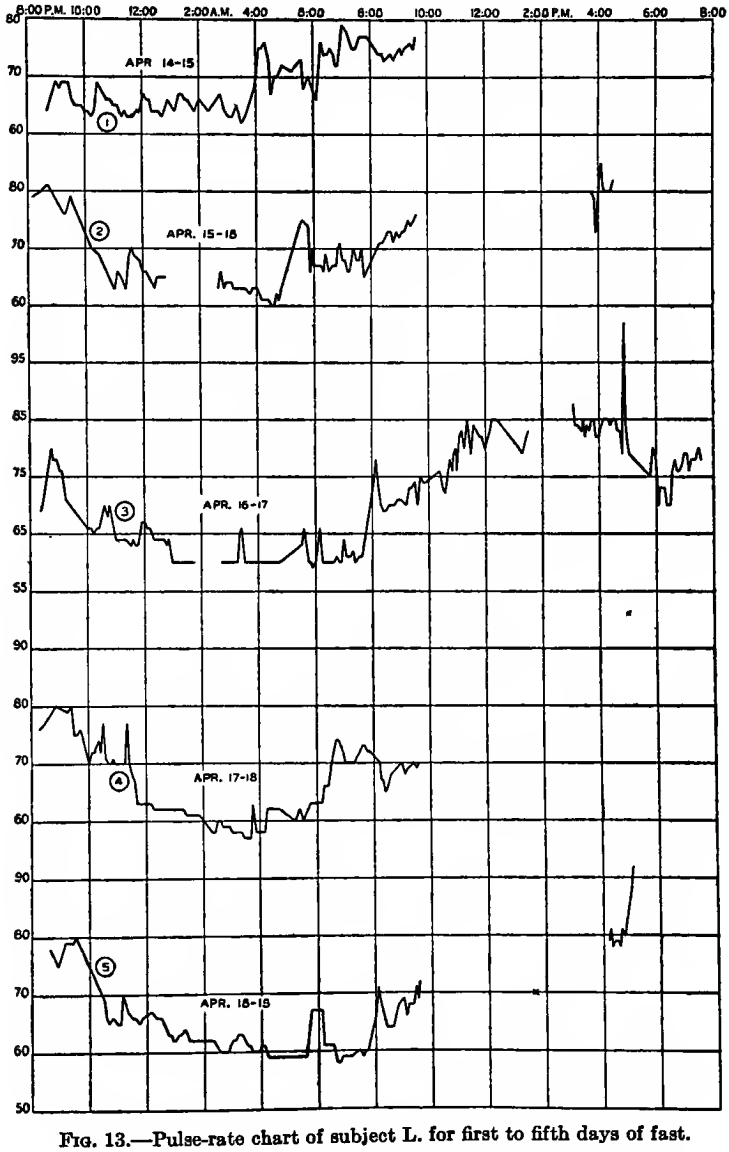


FIG. 13.—Pulse-rate chart of subject L. for first to fifth days of fast.

permissible to discuss these observations first, and later consider the more or less heterogeneous observations taken during the day when the activity might vary.

PULSE-RATE IN THE NIGHT PERIODS.

The relatively large fluctuations in the pulse-rate that are apparent in the first two or three nights are naturally to be explained by the fact that the subject was a stranger in America, and was experiencing for

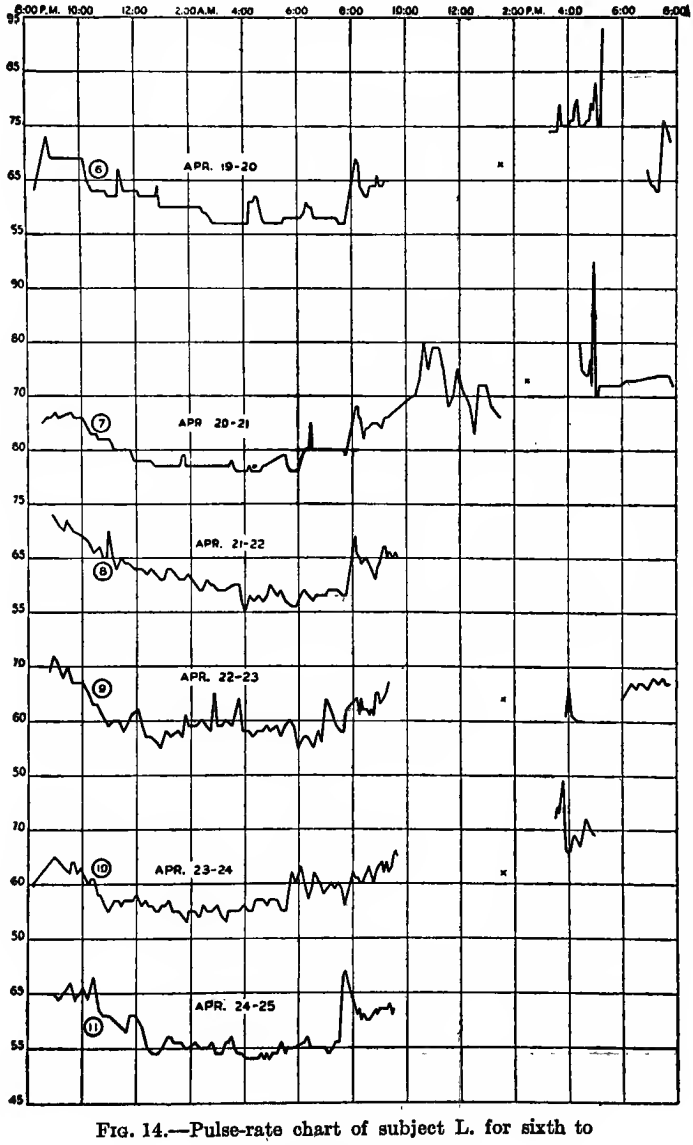


FIG. 14.—Pulse-rate chart of subject L. for sixth to eleventh days of fast.

the first time the novel sensation of being inclosed in the respiration chamber. On the night of April 14–15 (figure 13), we find reasonably constant pulse-rates until 4 a. m., when the observer's records show that he woke up, then dozed for the rest of the night. Usually the pulse-rate showed a tendency to fall prior to midnight, thereafter to continue fairly low until it rose again in the morning, although the period of minimum pulse-rate might continue for several hours. As the fast progressed, there was a marked tendency for the amplitude of

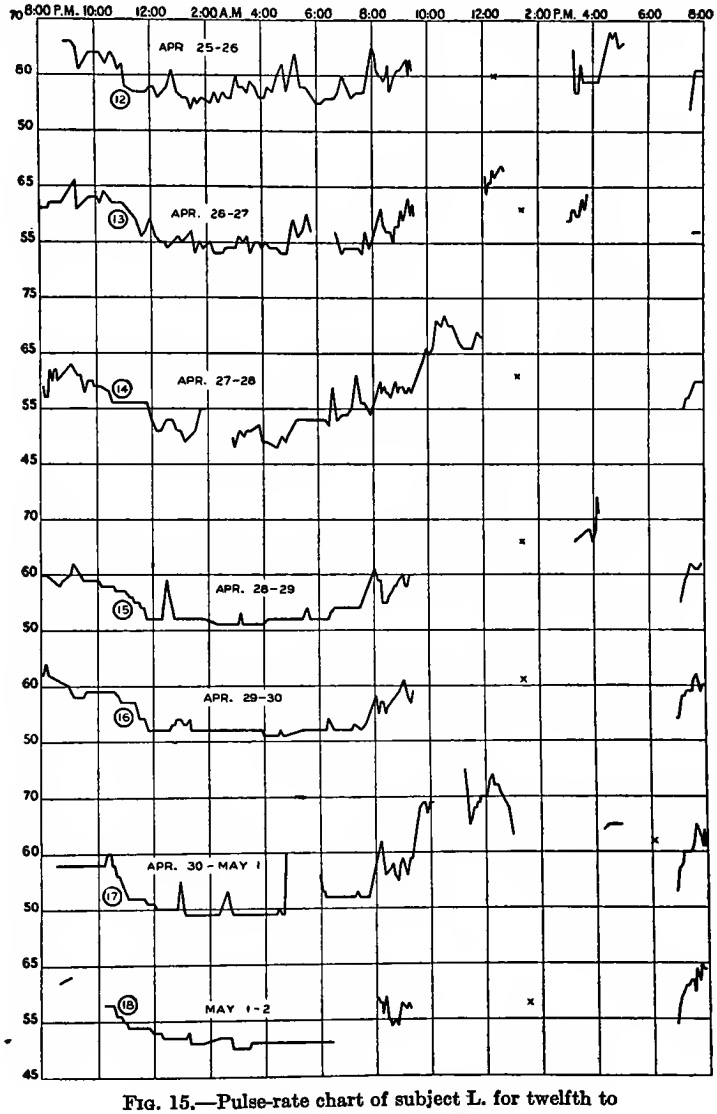


FIG. 15.—Pulse-rate chart of subject L. for twelfth to eighteenth days of fast.

the curve to become less and less—that is, the fluctuations from maximum to minimum throughout the night were less and the periods of reasonably constant pulse values grew longer and longer.

On the night of May 14–15, the last night of the fast (figure 18), special attention was given to the pulse-rate, the records being made frequently throughout the whole night. Although the curve is in con-

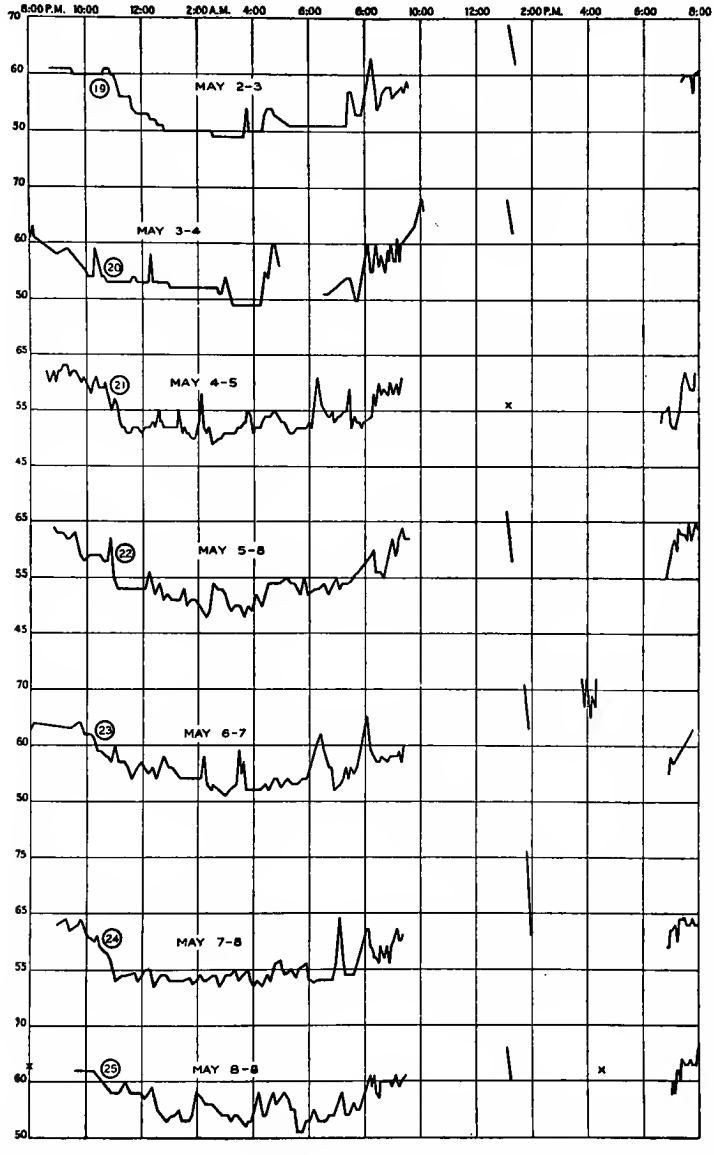


FIG. 16.—Pulse-rate chart of subject L. for nineteenth to twenty-fifth days of fast.

sequence irregular in shape, the general trend is not markedly different from those for the preceding and following nights. Even on May 15–16, the first night following the ingestion of food, although the subject was in such distress that he did not go inside the chamber, but lay on a couch outside, the frequent records of the pulse-rate did not show extraordinarily large fluctuations. On the night of May 16–17 relatively few records of the pulse-rate were taken; and also on May 17–18, but on this night we find a greatly increased amplitude. The general deduction is, therefore, that the amplitude of the fluctuations of the pulse-rate during the night decreased regularly as the fast progressed, showing a tendency upon the resumption of feeding to return to the variations commonly experienced.

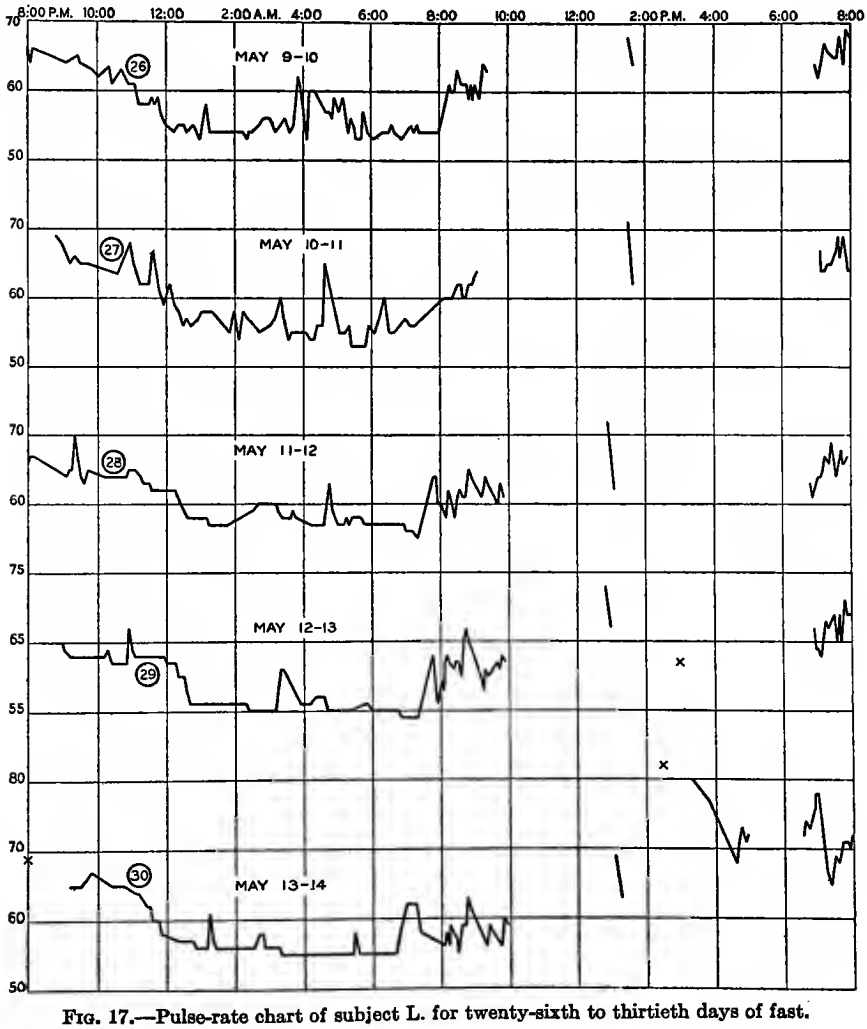


FIG. 17.—Pulse-rate chart of subject L. for twenty-sixth to thirtieth days of fast.

PULSE-RATE IN THE DAY PERIODS.

From 10 a. m. until 7 p. m., the records are naturally much less complete than the series obtained during the night; nevertheless on certain days reasonably complete records of the pulse-rate were obtained throughout the day.

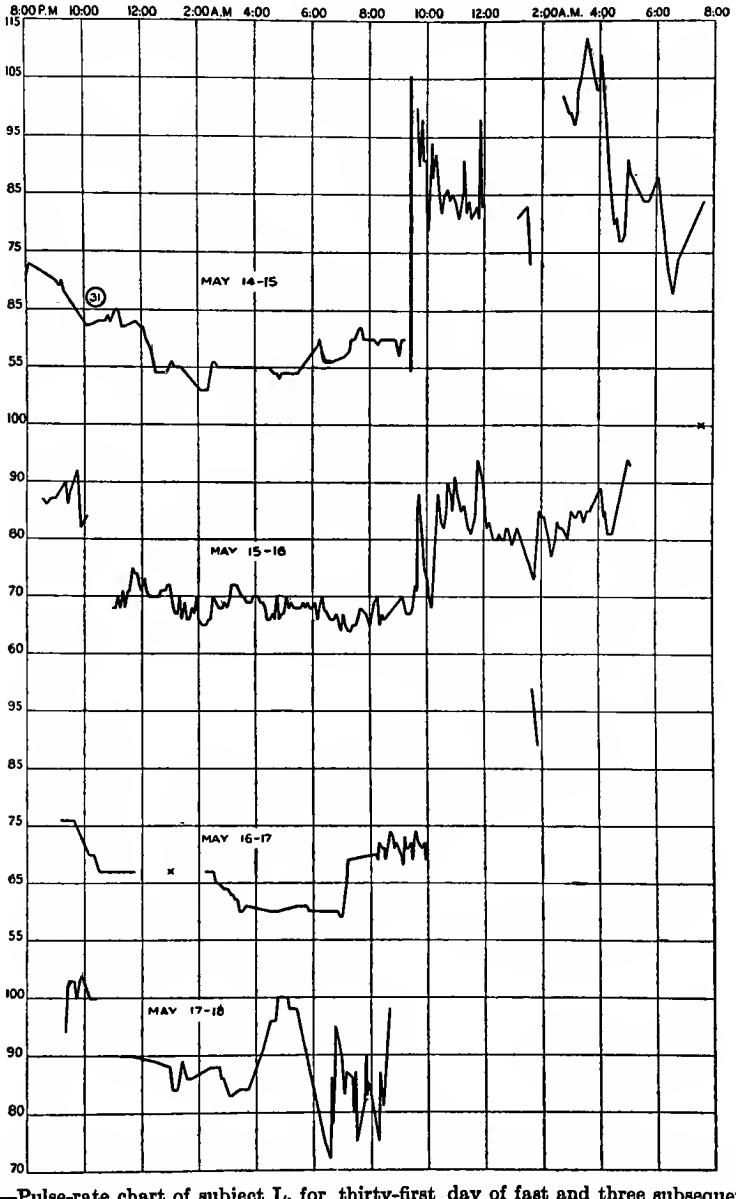


FIG. 18.—Pulse-rate chart of subject L. for thirty-first day of fast and three subsequent days with food. The point when the subject took food on May 14–15 is indicated by a heavy vertical line.

On April 16–17 (figure 13), the records were made for nearly the whole day, these values probably being fairly typical of records which would have been obtained if the observations had been more complete on other days. The minor fluctuations shown on April 16–17 are obviously due to changes in the activity of the subject when talking or moving about. The high values obtained about 5 p. m. are coincidental with the hand dynamometer test, in which there was some muscular exertion by the subject, the highest record at this time being 102. After the dynamometer test was over, the pulse-rate immediately fell again to an approximately normal level. Until $5^h\ 30^m$ p. m., the subject was lying on a couch and from $6^h\ 05^m$ p. m. was asleep in his chair for half an hour, the low level of the pulse-rate being apparent at this time. The records shown by the last portion of the curve were obtained during the evening respiration experiment. For the greater part of this day, the pulse-rate was on the average not far from 10 beats per minute above that which would ordinarily be found when the subject was lying upon a couch, although during muscular exertion, and especially after the dynamometer test, the pulse-rate at times tended to rise considerably above this value. The increase as a result of the dynamometer test may also be noted on April 18–19, April 19–20, and April 20–21.

Beginning with April 30–May 1, records were made each day not far from 1 p. m., at the time of the blood-pressure test. These records are of unusual interest, inasmuch as they indicate the values while the subject was sitting and again immediately afterwards when he lay down upon the couch. Thus, on April 30–May 1 (figure 15) the record for the sitting position was 68 and that for the lying position 63. These records, which appear with but few exceptions in the curves for the latter part of the fast, are of special interest, as they show the change in the pulse-rate due to change in position. This subject will be considered in a later section.

On May 13–14 (figure 17) a number of observations were made in the afternoon, one at $2^h\ 30^m$ p. m., while the subject was talking in a lively manner to an assembly of medical men. That the after-effect of this stimulus continued for some time is shown by the curve which follows. The fall in the pulse-rate, due to a change in position from sitting while writing to lying down upon the couch, is likewise shown, as between $6^h\ 20^m$ p. m. and 7 p. m. the subject was sitting up and writing and just afterward lay down upon the couch for a respiration experiment.

On the first day of realimentation, the curve (figure 18) shows very great fluctuations in the pulse-rate. These are in part due to the ingestion of food and in part to the pain and distress incidental to the colic resulting from the taking of a large quantity of acid material into the stomach and intestinal tract. As a matter of fact, the highest observa-

tions on this day were obtained at a time when there was a reasonably small amount of muscular activity. In a series of observations from $2^h 45^m$ p. m. until 4 p. m., which were made while the subject was sitting quietly eating an orange or drinking grape juice, a value of 112 was found. Even an hour after eating, when the subject had colic and was in much distress, the pulse-rate was considerably lower than during the period of eating, while the average value obtained when the subject was lying on the couch during a respiration experiment in the early morning was about 59. Evidently the process of eating or drinking, immediately following a prolonged period of inanition, increased the pulse-rate very greatly. On May 15–16, the second day of this period, the sharp rise in the pulse-rate incidental to taking food was likewise noted at $9^h 40^m$ a. m. and again at $11^h 46^m$ a. m. On May 17–18 the values obtained from 6 a. m. to 9 a. m. were unusually high, this being due in part to the fact that the subject was extremely excited and after the experimental period was over broke out into abusive language. There was undoubtedly a great increase in the psychic disturbance.

COMPARISON OF PULSE RECORDS OBTAINED IN EXPERIMENTS WITH THE BED CALORIMETER AND THE RESPIRATION APPARATUS.

While an examination of the general trend of the pulse curves shows admirably the tendency for the amplitude during the night to fall to a lower level, a comparison of the average values obtained under varying conditions can best be made in tabular form. Accordingly, in table 6 the average values are given for observations made when the subject was lying in the bed calorimeter and also the average of the records obtained when the pulse-rate had reached its lowest level during the calorimeter period. The values for the experiments with the respiration apparatus are likewise given, including those made in the morning, in the evening, when the subject was sitting quietly and also when writing. Furthermore, for purposes of comparison the pulse-rate records taken during the blood-pressure tests are included for both positions of sitting and lying. A number of important comparisons can thus be made.

During his stay in the bed calorimeter the subject was probably asleep for the greater part of the time—at least on many nights. On every night he had periods of wakefulness, which at times may have been of considerable length. Consequently not all of the values obtained in the bed-calorimeter experiments can be taken as actually obtained during sleep, but by examining the curves for these experiments it is relatively easy to select a value which probably represents the average minimum pulse-rate for this subject during sleep. These values are given in column B in table 6. Both the average night pulse-rate and the average minimum pulse-rate have a distinct tendency to decrease, as the fast progresses, until about the twenty-second fasting day. From

that time until the end of the fast the pulse records usually rise, so that at the end of the observations the average values are 3 or 4 beats higher than they were at the minimum point.

TABLE 6.—*Average pulse-rate of subject L. at different times of the day and with varying activity.*

Date.	Day of fast.	Lying.				During blood-pressure tests (about 1h 30m p.m.).		
		Bed calorimeter (usually 10 p.m. to 8 a.m.).		Respiration apparatus (subject awake).[1]	Increase with subject awake (C—B).	Sitting.	Lying.	Decrease with subject lying (E—F).
		Average. A	Minimum (subject asleep). B	C	D	E	F	G
1912.								
Apr. 10–11	.....	82	76	[2]72	−4	..	..	..
11–12	.....	76	70	[2]73	3	..	..	..
12–13	.....	78	73	[2]72	−1	..	..	..
13–14	.....	70	64	[2]73	9	..	..	..
14–15	1st..	68	64	74	10	..	..	..
15–16	2d...	66	63	73	10	..	..	..
16–17	3d...	62	60	70	10	..	..	..
17–18	4th..	65	58	68	10	..	..	..
18–19	5th..	63	59	67	8	..	..	..
19–20	6th..	60	57	64	7	..	..	..
20–21	7th..	59	56	64	8	..	..	..
21–22	8th..	61	58	65	7	..	..	..
22–23	9th..	59	57	63	6	..	..	..
23–24	10th.	57	55	63	8	..	..	..
24–25	11th..	57	54	61	7	..	..	..
25–26	12th..	58	56	61	5	..	..	..
26–27	13th..	56	54	59	5	..	..	..
27–28	14th..	53	51	58	7	..	..	..
28–29	15th..	53	51	57	6	..	..	..
29–30	16th..	53	52	58	6	..	61	..
Apr. 30–May 1	17th..	52	49	57	8	68	63	5
May 1–2	18th..	52	51	56	5	..	..	..
2–3	19th..	52	50	57	7	69	62	7
3–4	20th..	52	51	58	7	68	62	6
4–5	21st..	54	51	59	8	..	56	..
5–6	22d...	53	51	59	8	67	58	9
6–7	23d...	56	53	58	5	71	63	8
7–8	24th..	55	53	59	6	76	61	15
8–9	25th..	55	53	60	7	66	60	6
9–10	26th..	56	54	61	7	68	64	4
10–11	27th..	57	55	62	7	71	62	9
11–12	28th..	59	57	61	4	72	62	10
12–13	29th..	58	55	63	8	73	67	6
13–14	30th..	58	55	59	4	69	63	6
14–15	31st...	57	54	60	6	[3]83	[3]73	10
15–16[4]	.....	68	66	..	..	76?	73	3?
16–17	.....	64	60	[5]72	12	99	89	10
17–18	.....	90	84	[5]84	0	..	98	..

[1]The respiration experiments in the morning were usually made between 8h 30m and 9h 30m.

[2]During the respiration experiments in the morning on April 11, 12, 13, and 14 the subject was without breakfast.

[3]The subject had broken his fast by means of fruit juices during the morning.

[4]During the night of May 15–16 the subject lay on the couch in the calorimeter laboratory.

[5]During the morning respiration experiments on May 17 and 18 the subject was without breakfast.

TABLE 6.—*Average pulse-rate of subject L. at different times of the day and with varying activity*—Continued.

Date.	Day of fast.	Respiration apparatus.			
		Sitting.[1]		Lying (usually 7 to 7h 45m p.m.).	
		Period.	Average.	Average.	Increase over lying in the morning (I—C).
			H	I	J
1912.					
Apr. 15–16	2d	4h 00m p.m. to 4h 35m p.m.	82	..	..
16–17	3d		..	..	..
17–18	4th		..	..	..
18–19	5th	4 10 p.m. 4 43 p.m.*	80	..	..
19–20	6th		..	..	..
20–21	7th		..	..	..
21–22	8th		..	..	..
22–23	9th	3 52 p.m. 4 28 p.m.	62	..	..
23–24	10th	3 58 p.m. 4 57 p.m.	69	..	..
24–25	11th		..	..	..
25–26	12th	3 13 p.m. 4 11 p.m.	60	62	1
26–27	13th	12 14 p.m. 12 48 p.m.	68	[2]59	0
27–28	14th		..	59	1
28–29	15th	3 23 p.m. 3 56 p.m.*	68 ?	61	4
29–30	16th		..	59	1
Apr. 30–May 1	17th	9 31 a.m. 10 04 a.m.*	69	61	4
May 1–2	18th		..	62	6
2–3	19th		..	60	3
3–4	20th	9 35 a.m. 10 10 a.m.*	65	..	..
4–5	21st		..	57	−2
5–6	22d		..	63	4
6–7	23d	3 43 p.m. 4 14 p.m.*	69	60	2
7–8	24th		..	63	4
8–9	25th		..	63	3
9–10	26th		..	66	5
10–11	27th		..	66	4
11–12	28th		..	66	5
12–13	29th		..	67	4
13–14	30th	6 32 p.m. 7 02 p.m.*	75	71	12

[1]Periods indicated by an asterisk (*) were obtained with the subject sitting, writing.
[2]The average pulse-rate for a period 3h 16m p.m. to 3h 51m p.m. on this day with the subject lying on the couch was 61 per minute.

Any important deductions from average values for the night are out of the question on account of the irregularity in the number of the pulse records during the night and the impossibility of recording accurately the time when the subject slept and when he woke. If, however, we compare the values for the average pulse-rate with those for the average minimum pulse-rate, we find that about the middle of the fast the difference is only 1 or 2 beats. The greatest variation between these two series of averages is on the fourth day of fasting, when the average during the night was 65 and the average minimum value was 58. For further purposes of comparison, it is obviously more logical to use the average minimum values.

The pulse-rate during the respiration experiments is recorded with great frequency and regularity. Those obtained in the morning respiration experiments during the first period with food, *i. e.*, in the period preceding the fasting period, were invariably lower than the records obtained during the night experiments with the bed calorimeter, with the single exception of the fourth record, when the average pulse-rate for the night had a minimum of 64 and the average obtained in the respiration experiment was 73. Unquestionably the pulse-rate obtained during the night was influenced to a considerable extent by the food taken the day before, especially for the evening meal. In this connection it is of special interest to note that on the last night of this period the food taken in the evening meal was of such a character that the effect would be less prolonged. From this time on, the pulse-rate in the experiment with the respiration apparatus was invariably higher than the minimum pulse record obtained during the night. The difference in the early part of the fast was 10 beats, but then decreased until about the middle of the fast, when it fell as low as 5 beats. In the latter part of the fast it showed a tendency to increase again, although on the twenty-eighth and thirtieth days the difference was but 4 beats.

This difference in the pulse records is of great significance, indicating clearly an increased heart action, an increased muscle tonus, and, according to all previous experience in this laboratory, an increased metabolism. The question as to the influence of sleep on the pulse-rate and the metabolism has received considerable attention in this laboratory for a number of years and we find ourselves quite out of harmony with many European writers who maintain that sleep *per se* has no influence upon the pulse-rate and the metabolism. A subsequent examination of the records of the metabolism for this fasting subject bears out definitely our contention that there is a great difference in the pulse-rate and the metabolism in the waking over the sleeping condition.

INFLUENCE OF BODY POSITION.

In the latter part of the fast, the pulse-rate was recorded during the blood-pressure tests for both the lying and sitting positions. While the comparisons between the calorimeter experiments and the morning respiration experiments considered only the values secured when the subject was lying asleep or lying awake, these records obtained at noon indicate the change in the pulse-rate due to the change in the position from sitting to lying. The decrease in the pulse-rate is considerable, varying from 4 beats on the twenty-sixth day to 15 beats on the twenty-fourth day. A number of pulse records for the sitting position were also obtained with the subject in two morning and nine afternoon respiration experiments. In the morning experiments and also in four of the afternoon experiments, the subject was writing. On the afternoon of the second day of the fast, when the subject was sitting quietly,

the pulse-rate was as high as 82; the lowest observation was 60, which was recorded on the twelfth day of the fast.[1]

INFLUENCE OF THE WORK OF WRITING.

As the subject spent a considerable portion of the day sitting up writing, an effort was made to study the pulse-rate during a period of writing. Hence on a number of days the subject was connected with the respiration apparatus, the metabolism was studied, and records of the pulse-rate were taken. On two of the days these tests were carried out in the morning, immediately after the regular series of respiration experiments. On these two days—the seventeenth and twentieth days of the fast—the combined influence of this position and occupation was to increase the pulse-rate over the records obtained in the lying position, this increase being 12 beats on the seventeenth day and 7 beats on the twentieth day. Four experiments of this character were also made in the afternoon, but the pulse-rate showed little increase over records obtained in similar afternoon experiments when the subject sat quietly without writing.

INFLUENCE OF BREATHING AN OXYGEN-RICH ATMOSPHERE.

In an earlier series of observations of the pulse-rate in which normal subjects breathed an oxygen-rich atmosphere, there was a distinct tendency for the pulse-rate to decrease. Since it was of interest to note if this tendency to a decrease in the pulse-rate would be greater in prolonged fasting than under normal conditions, respiration experiments were made on the twenty-eighth, twenty-ninth, and thirtieth days of the fast, in which the subject breathed an oxygen-rich atmosphere and pulse records were simultaneously obtained. These experiments immediately followed the morning respiration experiments for those days in which the subject breathed air with a normal content, the average pulse records for the latter experiments being 61, 63, and 59 respectively. The pulse records in the experiments with the oxygen-rich atmosphere were as shown herewith.

Date.	Time of day.	Pulse-rate.
May 12....	$9^h\ 04^m$ a.m.–$9^h\ 48^m$ a.m.	62
13....	9 06 a.m.–9 52 a.m.	61
14....	9 16 a.m.–9 49 a.m.	58

From these results it appears that the pulse-rate in the high-oxygen experiment on the first day increased by 1 beat, on the second day decreased by 2 beats, and on the third day decreased by 1 beat. In former experiments[2] with normal individuals, the average decrease in

[1]The designation of the days for part of the data in table 6 is not in strict accordance with our method of ending the experimental day with the end of the morning respiration experiment, but the same numbering is used throughout for comparison purposes.

[2]Benedict and Higgins, Am. Journ. Physiol., 1911, **28**, p. 1.

the pulse-rate with the oxygen-rich atmosphere was not far from 5 to 6 beats, but with this fasting subject the inhalation of an oxygen-rich atmosphere apparently produced no change in the pulse-rate.

DIURNAL RHYTHM.

Beginning with the twelfth day of the fast, respiration experiments were made each evening, just before the subject entered the bed calorimeter. Comparing the records of the pulse-rate for these experiments with those obtained in the morning experiments, it will be seen that the pulse-rate in the evening was almost invariably higher than in the morning. While the difference in the middle of the fast is very slight, it tends to increase as the fast progresses, until on the thirtieth day there is a difference of 12 beats. On the twenty-first day the evening rate was 2 beats lower than that observed in the morning, the lowest pulse records for the evening experiments being found on this day.

IRRITABILITY OF THE HEART.

In all of the comparisons of the pulse records it is difficult to find any very definite indications of the so-called "irritable heart," especially emphasized by the Berlin investigators in their study of Cetti. It is true that the change from lying asleep to lying awake resulted in an increase in the pulse-rate, the difference in the fasting period being not far from 7 to 8 beats, with a maximum of 10 and a minimum of 4 beats. It is further true that the change from a sitting to a lying position, as noted at the time of the blood-pressure tests in the latter part of the fast, tended to decrease the pulse-rate from 4 to 15 beats per minute, averaging not far from 7 to 8 beats. Likewise, the pulse-rate in the evening respiration experiments averaged a few beats more than in the morning respiration experiments. But no great indication of an irritability of the heart was noted with any of these minor changes in position and activity.

On the food days, however, there was a great increase in the pulse-rate at the time the food was taken. Furthermore, the records obtained at the time of the blood-pressure observations show that the pulse-rate did not quickly return to the minimum after changing from a sitting to a lying position for the pulse-rate in the lying position is usually a few beats higher than the value obtained in the morning respiration experiments. Since the value for the lying position was found almost immediately after the test, it is hardly possible that the body had time to adjust itself to the position, but the tendency to reach the minimum found in the morning is worthy of note. Even with the slight activity due to the blood-pressure tests and changing the position, the pulse-rate is not so high as the pulse-rate obtained in the evening respiration experiments, showing that the prevailing diurnal variation was greater than that obtained with slight activity earlier in the day.

A point of considerable importance is the fact that there was a distinct tendency for the pulse-rate to reach a minimum between the fourteenth and twenty-second days of the fast, that is, during the third week. Consequently, all of the pulse records, including the average minimum records inside the bed calorimeter, the average for the calorimeter experiments, and the average for the morning respiration experiments, show a tendency to increase in the fourth week. The same tendency may be noted in the pulse records obtained at various times throughout the day. It is clear, therefore, that during the latter part of the fast the heart of the subject was in a somewhat more irritable condition than during the third week.

The observations on the pulse-rate in this fasting experiment have great significance when compared with the simultaneous measurements of the metabolism, as is done in subsequent sections of this publication. The records have therefore been presented *in extenso*, as they show strikingly that the pulse-rate may legitimately be used as an index of the metabolism. The total metabolism was measured only during the times when the subject was on the respiration apparatus or inside the bed calorimeter. For the remainder of the day, especially during those times when the subject was most active, the metabolism was not measured, so that the probable metabolism at these times must be estimated in so far as possible from the records of the pulse-rate. We therefore have little evidence of the effect of muscular activity upon the heart, except as shown by the few pulse records taken following slight activity. These do not indicate a distinctly irritable heart.

The muscular activity of the subject was probably greater at the time of the dynamometer tests than during any other observations. The relatively few records made before and after these tests show a distinct rise in the pulse-rate incidental to the dynamometer test, but also a very rapid return. Unfortunately they were not taken with sufficient regularity for us to note positively any indication of the increased or decreased irritability of the heart as the fast continued. It was the intention to study in this experiment the influence of light muscular activity upon the heart beat and the metabolism, but here again the unwillingness of the subject to engage in muscular activity of any kind prevented valuable observations originally planned for.

BLOOD PRESSURE.

As it seemed desirable to supplement the observations of the pulse-rate throughout the fast with observations of the blood pressure, the determinations were made by Mr. H. L. Higgins. In accordance with the advice of Dr. E. P. Cathcart, who had previously experimented with Beauté, the values were secured for both the lying and sitting positions, as it was quite possible that later in the fast it might be advantageous to keep the subject in bed. The records were made almost invariably shortly after noon and immediately after the subject had taken a glass of water. Employing the auscultatory method with the Erlanger sphygmomanometer, both the systolic and diastolic pressures were obtained.

In former fasts emphasis has been chiefly laid upon the determinations of the systolic pressure. Luciani, in using the sphygmomanometer of von Basch with an aneroid manometer, found that the variations in the blood pressure at the radial artery had a tendency to decrease as the fast continued, the decrease being from 220 mm. on the first day of fasting to 120 mm. on the twenty-sixth day. On the last four days of the fast there was a slight tendency for the pressure to increase. Luciani also states that there were daily fluctuations from morning to evening, which frequently, but not always, corresponded to changes in the temperature and the pulse-beat.

Cathcart,[1] using the C. J. Martin modification of the Riva-Rocci apparatus, found with Beauté a continual fall in the maximum pressure during the 14 days of the fast, his values being 108 for the first day and for the subsequent days 96, 98, 98, 92, 94, 88, 90, 88, 92, 88, 94, 90, and 88. These observations were always taken in the evening. Cathcart's determinations were controlled by Charteris,[2] who used the same instrument and presumably made the records at about the same time. The values differ but little from those reported by Cathcart, showing an excellent agreement of blood-pressure determinations by two observers. Charteris concludes that the pulse-wave became shorter and weaker, but remained regular in rhythm, and that the arterial pressure gradually sank so that at the end of the fast the fall amounted to almost 25 per cent of the normal reading. He noted a rapid recovery after the fast, the pressure being again practically normal after the first week of food.

In a 30-day fast reported by Penny,[3] in which he was himself the subject, the author states that the blood pressure was taken by a Martin's modification of the Riva-Rocci sphygmomanometer and fell

[1]Cathcart, Biochem. Zeitschr., 1907, **6**, p. 109.
[2]Charteris, Lancet, 1907, **173**, p. 686.
[3]Penny, British Medical Journal, 1909, p. 1414.

steadily during the fast from 110 to 90 mm. The daily observations are not recorded.

No direct blood-pressure measurements were made by the Berlin investigators on their fasting subjects, although from an examination of the pulse curves made with a Marey sphygmograph at the radial artery, Senator and Mueller[1] concluded that there was a noticeable decrease in the arterial tension which produced not only a dicrotism but likewise a decrease in the elasticity. This was more noticeable with a subject who fasted 10 days than with another who only fasted 6 days, notwithstanding the fact that on the last fasting day the pulse-rate was so weak that they could not secure a suitable curve.

The observations made of the blood pressure in the fasting experiment with our subject L. are given graphically in figure 19, the curves representing the systolic, diastolic, and pulse pressures for both positions of lying and sitting. With these are compared curves showing the average pulse-rate secured in the bed-calorimeter experiments throughout the night and also in the morning respiration experiments. During the latter part of the fast, the pulse-rate was likewise secured at the time the blood pressure was taken, in both positions of lying and sitting. These values are given in table 6 (pages 113 and 114).

As is usually the case, the systolic blood pressure when the subject was lying down was invariably somewhat higher than when the subject was in a sitting position, with a general tendency for the difference between the two to become greater as the fast progressed. On the last day of the fast, however, the difference was not much greater than at the first of the fast. The curves for the diastolic pressure also show higher values for the lying position, although the difference is not so great as with the systolic pressure, for up to about the fifteenth day the two curves are approximately the same.

The systolic pressure for the lying position falls quite rapidly through the first half of the fast, fluctuating considerably in the last half above or below the average value of 100 mm. of mercury. The records ranged from 134 mm. on April 16 to 94 mm. on April 30. An even lower value was obtained on May 16, 26 hours after taking food, namely, 92 mm. Two days later, however, it had increased to 124 mm.

The curve for the systolic pressure for the sitting position is nearly parallel to that of the systolic pressure for the lying position, although in the latter part of the fast the values were considerably lower and the fluctuations were not so great. The range in values was from 123 mm. on April 16 to 83 mm. on May 8. During the latter part of the fast it averaged not far from 90 mm.

The diastolic pressure for the lying position shows a marked fall from the third to the fourth day. Subsequently there is a gradual fall to the middle of the experiment, with a distinct tendency in the latter part of

[1]Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol. u. f. klin. Med., 1893, **131**, Supp. p. 101.

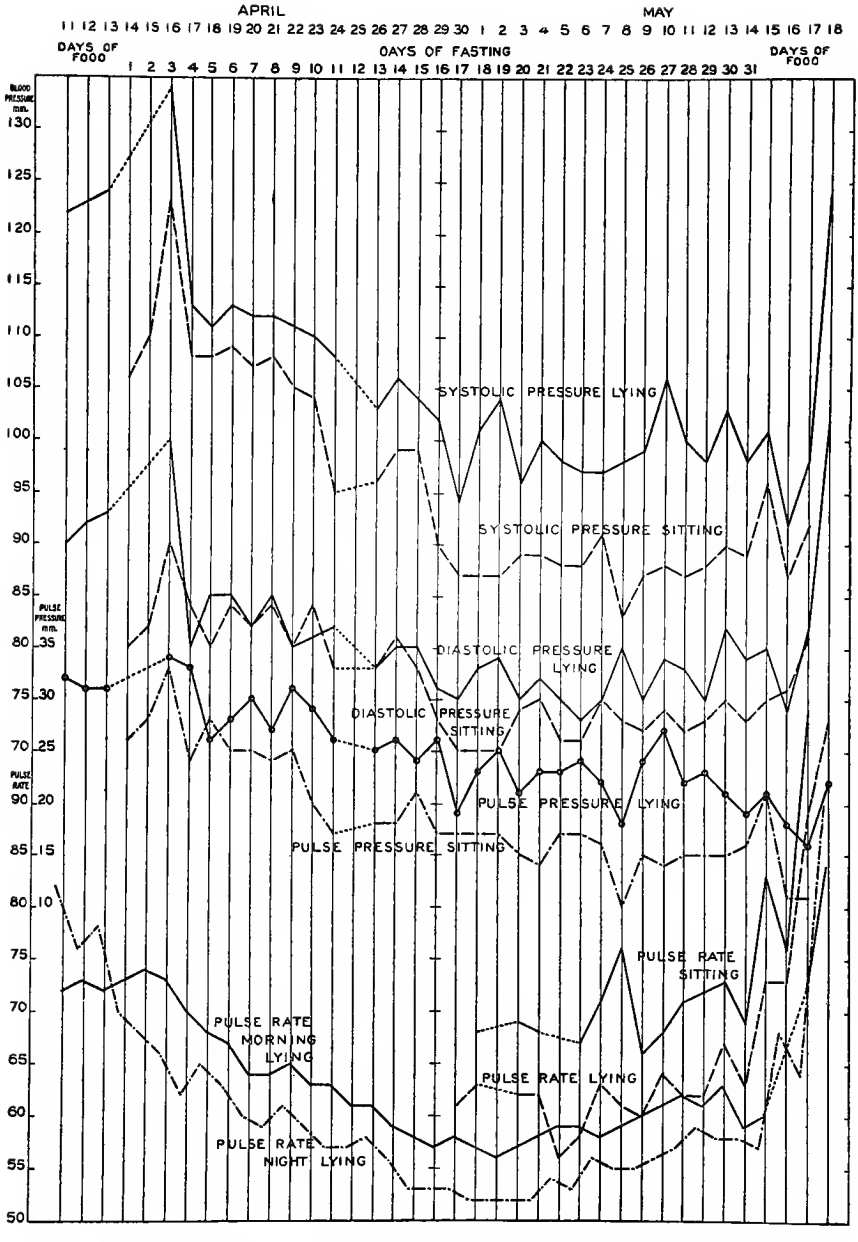


FIG. 19.—Chart showing blood pressure, pulse pressure, and pulse-rate of subject L.

the fast for the general course of the curve to rise. The highest record was 100 mm. on April 16 and the lowest was 73 mm. on May 6. Twenty-six hours after food was first taken the diastolic pressure in this position fell to 74, but it rose on the third day to 102 mm.

A similar course is followed by the curve for the diastolic pressure in the sitting position, although the fall from the third to the fourth day is not so pronounced. The slight tendency to rise in the last part of the fast is also shown in this curve. The highest record was 90 mm. on April 16 and the lowest was 70 mm., recorded on April 30, May 1, and May 2.

The general trend of all four curves for the systolic and diastolic pressures in the two positions is a distinct decrease in blood pressure during the first 15 days of the fast, followed either by an average constant value or a slight tendency for the pressure to rise in the last part of the fast.

With these observations of the systolic and diastolic pressure, it was possible to obtain the pulse pressure, this being the difference between the maximum and minimum blood pressures. According to some writers, the pulse pressure is of more significance than the blood-pressure observations themselves. An examination of the curves shows that the pulse pressure in the lying position was, except on one day, higher than the pulse pressure for the sitting position. The curves are by no means parallel, however, as there are great differences in the levels. The pulse pressure for the lying position decreases until the fifteenth or sixteenth day of the fast, and then fluctuates considerably, but averages approximately 23 mm. The pulse pressure for the sitting position shows a much more marked similarity to the trend of the blood-pressure curves, *i. e.*, a falling pressure until about the fifteenth day of the fast, followed by a period of approximately constant values, and finally a distinct tendency to increased pressure towards the end of the fast.

In considering the blood-pressure records, it is of interest to compare them with the average pulse-rate curves obtained in the bed calorimeter experiment during the night and on the respiration apparatus in the morning. These curves are given in the lower part of figure 19, and show a general parallelism with each other. Curves are also given showing the pulse-rate records for both positions obtained in the latter part of the fast at the time the blood pressure was taken. A fact of special interest in connection with these curves is that the average pulse-rate in the latter part of the fast has a tendency to rise during the calorimeter experiment and also in the morning respiration experiment. During the same period the blood-pressure curves remain essentially constant, showing only a slight tendency to rise, the pulse pressure for the sitting position alone having a tendency to follow more closely the average pulse record. From this it may be concluded that the pulse-

rate, which is considered in this laboratory as an index to the total metabolism, is not so indicative of the actual work of the heart as of the general metabolic tonus of the whole body.

The distinct decrease in blood pressure as the fast progressed may be due to one or both of two causes. The first is the decrease in the contractibility of the heart muscles as the fast continued and the second is the decrease in the general tone of the peripheral vessels. Luciani points out that theoretically the heart muscles should decrease more than any other muscles of the body, as they are continually at work, and that such a decrease has been found with fasting subjects. As will be seen from Dr. Goodall's report,[1] there was evidence of a distinct and regular decrease in the size of the heart during the fast. It is true that the decrease in the size of the heart observed by Dr. Bianchi, on Succi in his Florence fast, was not so great as that found by Dr. Goodall with L.; nevertheless the general conclusion in both series of observations is the same, namely, that there is a considerable diminution in the size of the heart as the fast progresses.

Somewhat in opposition to the belief that the size of the heart is the determining factor in the decrease in the blood pressure is the fact that on the third day after the fast the systolic and diastolic pressures had both returned to their normal level; the complete regeneration of the heart muscles in this time is difficult to conceive. A disturbing factor entered into the observations of the last day as the subject was laboring under intense psychical excitement.

[1]See page 65.

THE BLOOD.

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CORRELATION OF LITERATURE.

The blood has frequently been studied during inanition, but an exhaustive search through the literature brought to light only a few records of systematic examinations covering so long a period of fasting in man as the case that forms the basis of this report. Fasts of man conducted under scientific supervision and including blood examinations are limited in number, though the work on animals has been rather prolific. Before presenting the findings in Levanzin's blood, there is given a correlation of abstracts from this literature, of interest not only from an historical standpoint, but in demonstrating the diversity of results obtained by the various observers.

Among the earliest references are those to the work of Valentin[1] in 1838, who concluded that there was no alteration in the relation of blood-weight to body-weight as a result of exhaustive starvation, and that of Bidder and Schmidt,[2] in 1852, though these latter do not report anything more specific than an increase in the solid constituents in the blood of a starving cat. With reference still to the blood as a whole, London,[3] much later studying a series of 8 rabbits from which both food and drink were withheld, found a loss in total quantity, proportional, though, to loss of body-weight. Pashutin[4] concludes, as the result of the work of Heidenhain, Panum, and Voit, that the blood is not impoverished by fasting; on the contrary, in certain periods, the organism is plethoric. He holds it as remarkable that the number of erythrocytes increase—probably, however, only because of the rapid decrease in plasma. This latter fact is demonstrated markedly in the dogs observed by W. Müller and Buntzen,[5] though in none of their animals did a loss of more than 15 per cent in body-weight occur. Luciani[6] holds that, aside from water-content, the blood exhibits a resistance similar to the nervous system and that the apparent fluctuations, in corpuscular content at least, depend chiefly on the amount of water consumed. Chossat, however, quoted by Pashutin,[4] considered

[1]Valentin, Repel. f. Anat. u. Physiol., 1838, **3**, p. 156.

[2]Bidder u. Schmidt, Die Verdauungsfahrte in der Stoffwechsel, Mitau u. Leipzig, 1852, p. 328.

[3]London, Note sur la question du changement de la quantité générale et de l'alcalinité du sang dans le jeûne absolu. Arch. des Sciences Biol., 1895–96, **4**, p. 516. (Abstract by Mühlmann. See footnote 4, p. 125.)

[4]Pashutin, Pathological Physiology, Inanition. 1902, **2**, pt. I, p. 81 (Russian).

[5]Müller and Buntzen, Transfusion and plethora. Christiania, 1875.

[6]Luciani, Fisiologia del digiuno, Firenze, 1889. Authorized translation by M. O. Fraenkel. Das Hungern, Studien u. Experimente am Menschen, Hamburg u. Leipzig, 1890.

that, next to the fat, the blood suffered the greatest loss, amounting even to 75 per cent of its former weight. This view is not tenable in the light of practically all other work and was evidently the result of faulty technique or observations. Pashutin[1] quotes Valentin as noting striking general changes during hibernation—in part, that the blood putrefies from 2 to 4 times more slowly, that the arterial blood is not so bright a red, and that the venous blood is not so dark as normally, due to disturbance of oxygen interchange.

ERYTHROCYTES.

Considering more specifically the blood elements and beginning with the erythrocytes, we find that as early as 1843 Schultz[2] studied starving animals and found these cells atrophic, attributing the death of the animals to the inability of the shrunken cells to bind oxygen. Jones,[3] but a few years later (1856), observed that the corpuscles in dogs' blood appeared to have undergone "partial decomposition." Others since then have noted these striking alterations in shape and size of the corpuscles, among them Manasseïn,[4] Andral-Gavarret,[4] Laptschinski,[4] and especially Kagen,[5] who studied dogs and rabbits. He found little change in the first days, but as the fast progressed the red cells became smaller and crenated ones appeared more frequently, until at the end many "star forms" were seen and microcytes predominated. Liuboumdrow[6] also found variations in the character of the red cells—macrocytes, microcytes, and nucleated cells being common, especially the large form, which reached 20 to 30 per cent of the total red count.

In the roundabout way, we get from Pashutin[7] an abstract from Wratsch, 1881, p. 78, quoting from foreign journals (not specified) a reference to Dr. Tanner's blood after his 40-day fast in 1880. This was a public exhibition, but well controlled and was absolute for the first 15 days. The plasma and white cells presented nothing unusual. The red cells, however, were somewhat smaller than normal, being $\frac{1}{5000}$ inch in diameter instead of $\frac{1}{4000}$ to $\frac{1}{3000}$ inch.

Curtis[8] made systematic observations of Griscom's blood during his 45-day fast in 1880. This constitutes the longest period with blood examinations of which any record could be found.

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[1]Pashutin, Pathological Physiology, Inanition, 1902, 2, pt. 1, p. 81 (Russian).

[2]Schultz, Beitr. z. phys. u. path. Chem. von Simon, 1884 (quoted by Mühlmann. See footnote 4, this page.)

[3]Jones, Smithsonian Cont. to Knowledge, 1856.

[4]Mühlmann, Russisch Literatur über die Pathologie des Hungerns. Centralblatt f. allgem. Path., 1899, **10**, p. 160.

[5]Kagen, Blood and blood pressure in starving organisms. Dissert., St. Petersburg, 1884, Russian. From the Laboratory for General and Experimental Path., Prof. V. Pashutin, St. Petersburg.

[6]Liuboumdrow, Changes in the blood and organs in starvation. 71 Dissert., 1893, Russian. From the Path. Anat. Laboratory, Prof. W. Winogradow, St. Petersburg.

[7]Pashutin, Pathological Physiology, Inanition, 1902, 2, footnote p. 605 (Russian).

[8]Curtis, A study of blood during a prolonged fast. Proc. Am. Ass. Adv. Science, 1881, **30**, pp. 95–105.

Curtis describes the morphology of the erythrocytes as follows:

The first examination, made just after Griscom's last meal, showed the cells in abundance, of bright color, regular, smooth of outline, solid in appearance, and of usual size— $\frac{1}{3100}$ inch.

On the *third day* they were paler and apparently not so firm.

Fourth day: The change had progressed. There were two sorts of cells to be seen, one pale and large, the other deeper in color and contracted. Some of the former were almost invisible, appeared soft and sticky, enveloping objects encountered in flow. Their shape was altered to a round rim with abrupt descent to a flat floor. They averaged $\frac{1}{4000}$ inch. The other sort were deeper in color, less transparent than normal, and covered with nodules like blunt cones (*evidently crenated*). The cells had lost their usual concavity, and seemed as though acted upon by an astringent, being much smaller than normal— $\frac{1}{4400}$ inch.

Fifth day: The soft pale cells had disappeared, the smaller variety seemed larger and nodular. Irregularities in shape were first noticed, some cells being elongated, others lemon or club shaped, and still others had pointed ends.

Sixth to ninth days: The large soft form appeared and persisted in greater or less numbers. Later small colored bodies like red corpuscles appeared, measuring $\frac{1}{3300}$ inch. All the erythrocytes at this time were small. The extremely small ones continued to increase in number and diminish in size.

Sixteenth day: Corpuscle-like bodies observed as small as $\frac{1}{2000}$ inch. Those of $\frac{1}{6000}$ to $\frac{1}{6000}$ inch diameter were like normal red cells. Others were nodulated or of a chestnut-burr appearance.

Thirty-sixth day: "Saw an erythrocyte undergo direct division. From this day on, the red cells changed for the worse." They became pale, ragged and shrivelled. At this time the subject showed signs of weakened circulation— vertigo, numbness of hands and feet.

Thirty-eighth day: He fainted on rising from bed.

Thirty-ninth day: There was scarcely a normal corpuscle to be seen.

Fortieth day: After an excursion of $2\frac{1}{2}$ hours on the lake, there was a remarkable change in the blood picture. The ragged, pale, and broken corpuscles all disappeared and all the erythrocytes became smooth in outline and bright in color. They seemed quite normal, except that they were smaller, averaging $\frac{1}{3600}$ inch. After this, they again retrograded, became soft, pale, and sticky, but never so bad as just before the lake excursion. Certain minute granules were seen in this blood, granules which, in the author's experience, exist in all other persons, except one, whose blood was examined. They were small red points $\frac{1}{40000}$ inch in diameter and highly refractile. They are found also in lymph and cow's milk. They existed in the blood in great numbers at first, decreasing till after the eighth day; then disappearing until the twenty-fourth day, when a few pale ones appeared. They then increased in number, but only returned to their normal abundance after the fast was broken. (*These were apparently the platelets that he was observing.*)

This report is given in detail to illustrate not only the painstaking care with which the observations were made, but somewhat the comparative crudity of the methods employed at that time. As will be seen, it is only in the earlier reports that the appearance of macrocytes, microcytes, crenated and distorted cells are recorded, and it has occurred to the writer that with the improvement of blood technique the occasion for their presence was eliminated.

In 1887 Senator[1] reported finding a number of microcytes on the 13th day of a "Schlafsucht" in which a 54-year-old woman lay for about 7 weeks receiving as nourishment only a small amount of milk and wine. In Succi's[2] blood, late in the 40-day fast made as a public exhibition in London in 1890, numbers of imperfect blood disks were observed. Charteris,[3] on the other hand, could find no alteration in shape, size, or staining qualities of the erythrocytes in the blood of his human subject during the fast of 14 days in 1907, except that a few nucleated ones did appear during the last 4 days. Two examinations were made on Gayer's blood by Dr. Wile.[4] His was a public fast of 30 days, undertaken largely for advertising purposes. He drank water *ad lib.*, and though he was fairly well guarded, there was opportunity for his obtaining food secretly. However, at the beginning of the fast his weight was 210 pounds and at the end 174¾ pounds, a loss of over 35 pounds, which proves rather conclusively that the experiment was conducted in good faith. On the eighteenth day, the red cells numbered 5,192,000 and on the thirtieth, 5,776,000, a slight rise. The absence of anisocytosis or any degeneration of cells is mentioned specifically in the report. The subject refused to allow further examinations, particularly after breaking the fast, as desired by Dr. Wile in order to determine a normal picture. In none of the other reports are the characteristics of the individual red cell noted, so it is most likely that alterations of importance did not occur.

Continuing the consideration of the effects of inanition on the numerical estimation of the erythrocytes, the results are found to be at rather wide variance.

Senator[1] found no significant variation during the long period of almost complete inanition already mentioned above. He attributed little value to the small number of counts he made, but concluded there was probably a slight diminution. During Cetti's 10-day and Breithaupt's 6-day fasts, studied by Senator, Lehmann, *et al.*,[5] an increase was noted, amounting, in the former subject, to a million. Cetti's normal count of 5,720,000 was above the average. (Table 7.)

Dupérié[6] also claims that a considerable increase in number occurs. From the study of Succi's blood during a 30-day fast supervised by Luciani,[7] the latter concludes that the variations noted in numbers are

[1]Senator, Ueber einen Fall von sog. Schlafsucht mit Inanition. Charité-Annalen, 1887, **12**, p.316

[2]The fasting man. Brit. Med. Journ., 1890, **1**, p. 1444.

[3]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, **2**, p. 685.

[4]Gayer's fast: A private communication from Dr. Wile, of New York City.

[5]Lehmann, Mueller, Munk, Senator, and Zuntz, Untersuchungen an zwei hungernden Menschen. Archiv f. path. Anat. u. Physiol., Virchow's, 1893, **131**, supphft., p. 1.

[6]Dupérié, Sur les variations physiologiques dans l'état normal des globules du sang. Paris, 1878. Cited by Rollett in Hermann's Handbuch d. Physiolog., **4**, (1).

[7]Luciani, Fisiologia del digiuno, Firenze, 1889. Authorized translation by M. O. Fraenkel. Das Hungern, Studien u. Experimente am Menschen, Hamburg u. Leipzig, 1890.

only relative, depending on the concentration or dilution of blood from alteration in water-content. While on the twenty-seventh day the greatest loss was noted, there followed on the twenty-ninth day a rise that brought the number to the level of the first day. Andreesen,[1] Malassez,[1] and Lépine[1] found that while in the beginnings of the fasting periods there would be an increase in number, in the later days a decrease occurred.

TABLE 7.—*Red-cell counts on Cetti and Breithaupt.*

Day.	Cetti.	Breithaupt.
Before fast.....	5,720,000	4,953,200
3d fast.....	.....	5,184,000
4th fast.....	5,285,000	.....
6th fast.....	.....	[1]4,801,000
9th fast.....	6,830,000	.....
Broke fast.....	.....	[1]4,820,000
2d diet.....	6,560,000	4,812,000
2 weeks later.....	5,730,000	.....

[1]Before and after first meal on the sixth day.

Clinical records furnish us with the two following reports of relevant interest. The first is of one of Landouzy's patients studied by Malassez.[2]

"A boy of 18 lived 3 months and 20 days with a stricture of the esophagus, the result of swallowing H_2SO_4. He obtained practically no nourishment, as he vomited food administered by tube. Ten days before death, he began to take a small quantity of milk and meat. The red cells numbered 3,600,000 20 days before death, and a week before the end 2,600,000, a decided loss from normal. Two days before the boy died, the count had risen to 3,200,000. A transfusion was performed immediately after this examination, followed in 20 minutes by another count which showed a rise to 3,500,000. The next day they had returned to 3,200,000."

This is a striking loss, and while it is not possible to rule out a toxic influence in this case, the almost complete inanition was no doubt the prominent factor.

"The second case (reported by Brouardel)[3] was a man of 48 years, who lived 4 months 12 days after an experience similar to that just quoted. But one blood examination was made, and that 2 days before death, when the erythrocytes were 4,849,000 and the leucocytes 7,852."

While to the present writer these would be considered as practically normal counts, the author of the report concludes that they demonstrate a concentration of the blood.

[1]Mühlmann, Russiche Literature über die Pathologie des Hungerns. Centralblatt f. allgem. Path., 1899, **10**, p. 160.
[2]Malassez, Bull. et mém. de la soc. méd. des hôpitaux de Paris, 1874, **11**, p. 124.
[3]Brouardel, Union Méd., 1876, ser. 3, **22**, p. 408.

Von Noorden[1] has found the corpuscular content normal in five cases of gastric ulcer with emaciation. He remarks that in spite of the anæmic appearance presented by patients suffering from various conditions causing malnutrition, their blood is usually normal. This of course does not hold in those cases where the cause of the malnutrition has a direct

TABLE 8*a*.—*Estimations of red cells during Griscom's fast (Curtis).*

Day.	Estimation of red cells.	Remarks.
4th.....	4,320,000	
5th.....	4,485,000	
6th.....	2,370,000	
8th.....	4,860,000	
10th.....	3,260,000	
11th.....	4,720,000	
12th.....	3,790,000	
13th.....	4,480,000	
14th.....	4,210,000	
15th.....	2,800,000	
18th.....	5,790,000	
19th.....	6,770,000	
20th.....	6,500,000	Flatulence. Patient felt quite ill; took enema, causing stool.
21st.....	5,600,000	
22d.....	2,100,000	
23d.....	5,460,000	
24th.....	5,420,000	
25th.....	3,920,000	These figures are not entirely destitute of symmetry.
26th.....	4,160,000	
27th.....	2,540,000	
28th.....	3,130,000	
29th.....	3,180,000	Counts on 6 intervals of 6 days.
30th.....	3,180,000	10 " " 4 "
31st.....	3,360,000	15 " " 5 "
32d.....	4,420,000	22 " " 7 "
33d.....	3,600,000	27 " " 5 "
34th.....	3,900,000	37 " " 10 "
35th.....	3,700,000	40 " " 3 "
36th.....	3,810,000	44 " " 4 "
37th.....	3,520,000	Pointing to the opinion held of a certain limited duration of life of red blood corpuscles.
38th.....	4,080,000	
39th.....	4,200,000	
40th.....	3,200,000	
41st.....	3,390,000	
42d.....	3,590,000	
43d.....	3,490,000	
44th.....	3,150,000	
45th.....	5,390,000	

influence on the blood, as in infections. He discusses this practical phase of the subject and gives many references to observations of the effects on the various properties and constituents of the blood of "clinical" inanition.

[1]Von Noorden, Metabolism and practical medicine, Anglo-American issue, Chicago, 1907, 2, p. 28.

Returning to Curtis's[1] article, we find the following protocol (table 8*a*) of the 38 numerical estimations made of the red cells during the 45-day fast of Griscom, with the former's comments.

"The subject was at his worst physically and mentally between the twenty-seventh and fortieth days, and during this period the counts were consistently low. On the fortieth day he took the excursion on the lake, which was apparently the cause of the drop of 1,000,000 from the count of the preceding day. It will also be noted that for the few days before a decided fall in number there was usually a rise. The corpuscles on the days of these low counts always appeared healthier than at other times. On the last day Mr. G. drank no water and the high count of that day may have been due to concentration."

Kagen,[2] in 1884, claimed that the ordinary methods of determining the cell content of blood were open to so many sources of error that the results were not dependable. He limited his observations, therefore, to the direct estimation of the solid constituents, the specific gravity (by pyknometer), and hæmoglobin content (Malassez's hæmochromometer). He examined 6 dogs and found in the early days an increase in all three factors, attributing the changes to concentration through water loss. The amount of solid constituents, he claims, can equal even at the end of the fast that present under normal conditions. Liuboumdrow[3] noted, as an average of observations on 17 dogs, a slight increase in erythrocytes till the loss of body-weight amounted to 10 to 15 per cent, then a steady decrease till death, the diminution amounting to as high as 32 per cent on the twenty-eighth day. Nasse[4] also found an increase in number in a dog after 11 days of complete fasting. As proof that this was due to variation in water-content, he states that he obtained a reaction in the opposite direction when the animal was again allowed water.

Polétaëw[5] studied 8 dogs that received neither food nor water, dying after loss of 50 per cent in body-weight. These all showed an increase in red cells until late in the fasts, after a loss of 30 per cent body-weight, when there was a gradual decrease till death. Polétaëw is not satisfied with the explanation of this finding simply on the grounds of concentration, for he found an increase also in the dogs that were allowed water. He holds that while there may be interference with blood formation, there is also less destruction for bile formation. Tauszk,[6]

[1]Curtis, Physiology of autonutrition; A study of blood during a prolonged fast. Am. Ass. Adv. Science, 1880, **30**, pp. 95–105.

[2]Kagen, Blood and blood pressure in starving organisms. Dissert. St. Petersburg, 1884, Russian. From the Laboratory for General and Experimental Path., Prof. V. Pashutin, St. Petersburg.

[3]Liuboumdrow, Changes in the blood and organs in starvation. 71 Dissert., 1893, Russian. From the Path. Anat. Laboratory, Prof. W. Winogradow, St. Petersburg.

[4]de Martigny u. Nasse, Ueber den Einfluss der Nahrung auf das Blut. Marburg u. Leipsic, 1850.

[5]Polétaëw, The morphologic composition of the blood in complete and incomplete starvation in dogs. Dissert. 97, 1894, St. Petersburg (Russian). From the Laboratory of Path. Anat., Prof. Uskow, Riv. internaz. d'ig., Roma, '95, **6**, p. 129, and Arch. d. sc. Biol. St. Petersburg, 1893. **2**, p. 794.

[6]Tauszk, Jahrsb. über d. Fortschr. der Thier-Chemie, 1894, **24**, p. 147; abstracted from Orvois hetilap, Budapest, 1894, p. 512. Also Haematologische Untersuchungen am hungernden menschen. Wien. klin. Rundschau, 1896, **10**, p. 306.

in a study of Succi's blood during his 30-day fast in 1894, found, after a short interval of decrease, a moderate increase in the red cells. (See table 8 *b*.) The form of the cells remained normal to the end.

Daiber[1] in 1896 drew his conclusions as to the effect of inanition on the blood from his findings in Succi's urine during a 20-day fast. There was an increase in urobilin and earthy alkaline phosphates, both of which were to be accounted for by assuming an enormous destruction of erythrocytes, though he does concede that the phosphates might have come from tissue destruction elsewhere. As proof of the adaptability of the blood to altered conditions, he presents the decrease in urobilin and disappearance of phosphate sediment noted after the fifth day, showing an acquired resistance to the previously destructive influence of fasting. The urobilin was distinctly demonstrable through-

TABLE 8 *b*.—*Succi's red-cell counts.*

Day.	Red cells.	Ratio of red to white cells.
Third.....	5,246,000	1 : 545
Eighth.....	4,840,000	1 : 584
Thirteenth...	4,932,000	1 : 684
Seventeenth..	5,136,000	1 : 744
Twenty-first..	5,160,000	1 : 938
Twenty-fifth..	5,268,000	1 : 1097
Thirtieth....	5,472,000	1 : 1302

out the fast, though greatly reduced, but the phosphate sediment was replaced by one of urates. The plasma remained intact, as no transudation of its constituents, particularly albumen, through the kidneys could be demonstrated. Daiber concludes that the conditions during inanition must resemble those present in continued fevers in which there is usually red-cell destruction sufficient to give rise to a demonstrable anæmia. In these cases urobilin is present in the urine in distinctive amounts.

In the dog which died on the twenty-fifth day, after a loss of 52 per cent in body-weight, Hayem[2] reports an increase till the eighteenth day from 4,200,000 to 5,500,000. There was then a slight decrease, though at the end the erythrocytes numbered 4,800,000, still above the original count. The hæmatoblasts decreased continually during the fast. Reyne[3] found a progressive increase in the number in a dog dying on the twenty-fifth day of starvation. Charteris,[4] on the other

[1]Daiber, Beitrag zur Kenntniss des Stoffwechsels beim Hungern. Schweitzer Wochenschr. f. Chem. u. Pharm., Zurich, 1896, **34**, p. 395.

[2]Hayem, Leçons sur les modifications du sang. Paris, 1882, p. 382.

[3]Reyne, quoted by E. Bardier in his article on Inanition, in Dictionnaire de Physiologie, Charles Richet, **9**, p. 99.

[4]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, **2**, p. 685.

hand, in the case of his already mentioned, could find no suggestive variation, though there was some daily fluctuation.

Gordon[1] studying the blood of Martin, a medical student who underwent a 9-day fast with the uniform daily water consumption of 24 ounces, could find practically no variation in red-cell count, except that on the sixth day of refeeding it was about 1,000,000 below the normal. At the end of the first week of Succi's fourth fast, one of 40 days conducted in London,[2] the red cells numbered 6,500,000, an increase of 1,000,000 over the average normal individual's count. It may be more or less in this particular case, as the normal count is not given. A. R. Diefendorf, however, found a slight diminution during and a relatively rapid rise immediately following each of the two fasts of a man of 7 and 4 days interrupted by a feeding period of 19 days, which formed the basis of Benedict's[3] report.

Three counts were made on the blood of Dr. Penny,[4] who fasted for 30 days, in 1909, drinking only distilled water. They demonstrated a moderate increase till the twentieth day and a loss of 1,000,000 during the remaining 10 days. Here again no normal count was obtained. The results for the three counts were for the twelfth day, 6,600,000; twentieth day, 7,000,000; thirtieth day, 6,000,000. Ronsse and van Wilder[5] hold there will always be a slow increase in erythrocytes if water as well as food is withheld.

Though the conditions are not altogether analogous, it is interesting to note that in hibernating animals there is a decided decrease in erythrocytes, as is reported by Ranke.[6]

HÆMOGLOBIN.

Senator, using the v. Fleischl method, noted a moderate increase in his woman subject[7] and in Breithaupt;[8] a loss, however, of about 20 per cent in Cetti[8] in 9 days. (Table 9.)

Liuboumdrow[9] (with Malassez's method) found a slight increase in the blood of dogs until a loss of 10 to 15 per cent of body-weight had occurred, when a decrease was recorded that progressed until the animals died.

Benedict[3] reports a slight loss during, with a rise after, the fasts, corresponding to the fluctuations of the erythrocytes. The v. Fleischl and Tallqvist methods were used.

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[1]Gordon, A prolonged fast. Montreal Med. Journ., 1907, **36**, p. 482.

[2]The fasting man. Brit. Med. Journ., 1890, **1**, p. 1444.

[3]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 322.

[4]Penny, Notes on a thirty-day fast. Brit. Med. Journ., 1909, **1**, p. 1414.

[5]Ronsse et van Wilder, Variations du nombre des globules rouges et du taux de l'hemoglobine au cours de l'inanition chez le lapin. Arch. intern. de Pharm. et Thér., 1903, **11**, p. 301.

[6]Ranke, Grundzüge der Physiolog., 3d ed., p. 380.

[7]Senator, Ueber einen Fall von sog. Schlafsucht mit Inanition. Charité-Annalen, 1887, **12**, p. 316.

[8]Lehmann, Mueller, Munk, Senator, and Zuntz, Untersuchungen an zwei hungernden Menschen. Archiv f. path. Anat. u. Physiol., Virchow's, 1893, **131**, supphft., p. 1.

[9]Liuboumdrow, Changes in the blood and organs in starvation. 71 Dissert., 1893, Russian. From the Path. Anat. Laboratory, Prof. W. Winogradow, St. Petersburg.

Martin's[1] hæmoglobin was 90 per cent the first day, 95 per cent the fourth, and 90 per cent again on the last day, the ninth, dropping to 80 per cent 6 days after resuming food.

Penny[2] showed an increase of 8 per cent during his 30-day fast, going from 104 to 112 per cent.

TABLE 9.—*Haemoglobin estimations on Cetti and Breithaupt.*

Day.	Cetti.	Breithaupt.
	Per cent.	*Per cent.*
Before fast	115 – 118	107
Second day	...	114
Third day	...	114
Fourth day	110	110
Sixth day (before first meal)	...	130
(2 hours after first meal)	...	116
Ninth day	85 – 90	...
Second day of diet	...	114

In Luciani's[3] report is to be seen a variation synchronous with that of the erythrocytes, except on the eleventh and thirteenth days, when the percentage failed to rise with them. There was a small increase on the third and twenty-first days and it was lowest on the thirteenth and twenty-sixth days. The highest estimation was 90 per cent, the lowest 72 per cent (v. Fleischl apparatus). He concludes that there is an actual loss of hæmoglobin. Quoting his studies with Bufalini, carried out in Sienna in 1882, on a dog that lived 53 days without food, he states there was a rapid rise during the first 6 days. (Modified Bizzozero's method used). This he explains as being due not only to concentration from loss of water, but to the more rapid consumption of plasma than corpuscles. The initial rise was followed by a gradual decrease continuous until the last 12 days of the fast, during which the percentage was constant.

Gayer's[4] percentage rose from 80 on the eighteenth day to 100 on the thirtieth, when his fast was broken.

Charteris,[5] reporting the 14-day fast, notes a drop from 110 per cent to 96 per cent, after remaining unaffected for the first few days. The loss was not recovered until several days after breaking fast.

Subbotin,[6] using Preyer's method (spectroscope), found a decrease of hæmoglobin in a case fed on nitrogen-free diet. By the twenty-sixth day it had fallen from 13.80 per cent to 11.65 per cent and on the thirty-

[1]Gordon, A prolonged fast. Montreal Med. Journ., 1907, **36**, p. 482.
[2]Penny, Notes on a thirty-day fast. Brit. Med. Journ., 1909, **1**, p. 1414.
[3]Luciani, Fisiologia del digiuno, Firenze, 1889. Authorized translation by M. O. Fraenkel. Das Hungern, Studien u. Experimente am Menschen, Hamburg u. Leipzig, 1890.
[4]Gayer's fast: A private communication from Dr. Wile, of New York City.
[5]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, **2**, p. 685.
[6]Subbotin, Zeitschr. f. Biol., 1871, **7**, p. 187.

eighth it was 9.52 per cent. In starving rabbits, however, there was an increase due (he concludes) to decrease in water-content of the blood. In a dog that starved for 38 days there was very little variation, from 13.80 at the beginning to 13.33 per cent at the end.

Though the inanition was only partial, the experiment of v. Hösslin[1] is suggestive and his conclusions are interesting. He observed two growing dogs, one of which, (*a*), weighing 3.2 kilograms, was given only one-third the nourishment that (*b*), weighing 3.1 kilograms, received. Table 10 presents the results:

TABLE 10.—*Results of v. Hösslin's observations.*

Dog.	56th day.		124th day.			18 months.		
	Kilos.	Percentage of hæmoglobin.	Kilos.	Percentage of hæmoglobin.	Erythrocytes.	Kilos.	Percentage of hæmoglobin.	Erythrocytes.
(*a*) Underfed.....	5.5	11.2	8.5	16.0	7,970,000	9.5	15.5	7,300,000
(*b*) Normal.....	11.6	10.2	23.4	14.9	6,820,000	30.3	17.6	8,300,000

The difference in hæmoglobin content of the two dogs, in spite of extreme emaciation in dog (*a*), is still within physiological limits, proving how independent of the *amount* of nourishment the hæmoglobin really is. He claims a greater influence on the blood constituents through the *nature* than the *amount* of nourishment, long-continued impoverishment in albumen, *e. g.*, causing a decrease in both hæmoglobin and red cells. We do wrong, he claims, to consider as a result of the malnutrition the apparent or real anæmia seen in poorly nourished individuals. Either it is only (1) apparent, the hæmoglobin and red-cell content remaining high while the patient appears anæmic from contraction of peripheral vessels in an effort to compensate for the lessened thermogenesis, or it may be (2) actual anæmia, the result, however, of the condition that is responsible for the malnutrition, *e. g.*, long-continued fever, cancerous ulcers, repeated hæmorrhages, intestinal parasites, etc. The amount of nutrition, however, has a great influence on blood formation, so that anæmia, from whatever cause, will clear up much more readily under good than poor nourishment. The effect of uncomplicated inanition, therefore, is to reduce the total quantity of blood as it does the muscle and organ volume generally, rather than disturb the individual constituents. On refeeding, this total quantity is restored quickly, so that there appears an anæmia, in spite of the better nourishment—a relative condition, however, due to

[1] v. Hösslin, Ueber den Einfluss ungenügender Ernährung auf die Beschaffenheit des Blutes. Gesellschaft f. Morphologie u. Physiol., Munich, 1890, p. 119.

more rapid restoration of fluid than hæmoglobin and cellular elements and apparent till the normal relation is established.

Gallerani[1] found that the mean resistance of the hæmoglobin of dogs and frogs to solutions of NaCl of various percentages was increased during fast; the resistance to the high percentage solutions decreased, while to the low it increased. The former was due, he claimed, to the absence of newly formed hæmoglobin, which is more resistant to the stronger solution and the latter to the absence of very old or much used hæmoglobin, which is less resistant to the weak solution.

Hermann[2] in discussing the subject, says that the changes found with the ordinary methods of examination can well be due to concentration, because the water is the most variable of the blood constituents. Results are conclusive, therefore, only when they deal less with the hæmoglobin content than with the relation of hæmoglobin to the total quantity of solid constituents.

Groll's[3] work was carried out on this line with rabbits, cats, and one dog. Their fasts were absolute, no water being allowed. They existed under these conditions for from 1 to 22 days. He estimated the hæmoglobin quotient by dividing the percentage of hæmoglobin, as determined by the v. Fleischl apparatus, by the percentage of solid constituents. The latter was obtained by heating measured quantities of blood to 110° C. till the weight remained constant. With few exceptions the color quotient thus found was increased. The simple hæmoglobin per cent showed a rise in all the animals, being, however, only a relative increase, due to concentration of the blood. The diminution in the total solids was due to the greater susceptibility to destruction of the other solid constituents. During the period of restitution, there was a diminution in the hæmoglobin. This, again, was largely a relative change, occurring as a result of dilution from increased water intake, though no doubt the hæmoglobin is slower in regenerating as well as being more resistant to destruction. Groll concludes that the hæmoglobin is more stable in starving conditions than any of the other solid constituents of the blood.

It would seem from these data that the red cells and hæmoglobin are particularly resistant, though in the long fasts there is no doubt a slight loss of both elements. The consensus of opinion appears to be that concentration of the blood through water loss is responsible for the increase found during the fast and that dilution from more rapid return of water than the other elements accounts for the decreases found immediately after the fasting.

[1]Gallerani, Resistenz des Hæmoglobins im Hunger. Jahrsb. u. die Fortschr. der Thier-Chemie, 1894, **24**, p. 120. (Abstracted from Ann. di chim. Farmacol., 1892, **15**, p. 3.)

[2]Hermann, Untersuchungen über den Hæmoglobin-Gehalt des Blutes bei vollständiger Inanition. Dissert., Königsberg i. Pr., 1887.

[3]Groll, Untersuchungen über den Haemoglobin Gehalt des Blutes bei vollständiger Inanition. Dissert., Königsberg i. Pr., 1887.

LEUCOCYTES.

More attention has been paid to the white cells than to any of the other blood constituents and reports are more at variance as to just what does happen to them during states of inanition. Almost every possible change, especially numerical, has been observed at one time or another.

Morphologic alterations are recorded by Luciani,[1] who noted an early decrease in size, so that by the fifth day all the leucocytes were smaller than the red cells. They recovered their normal size by the ninth day, however.

Charteris,[2] on the other hand, mentions specifically that he observed no alteration in size.

Manassein[3] reports the presence in the leucocytes of fasting rabbits of refractile bodies that are not affected by acetic acid.

Källmark[4] observed, in his rabbits, rarefaction in the basophiles, with agglutination and peripheral arrangement of the granules.

Curtis,[5] in 1880, observed peculiar bodies, resembling leucocytes but larger, consisting of spherules too small to measure. These cells measured $\frac{1}{2000}$ inch in diameter and exhibited amœboid movement. When these very indefinite bodies were most abundant, the granules were absent from the leucocytes. Curtis does not speculate as to whether these were altered white corpuscles or a foreign cell entering the blood from the tissues.

Hayem[6] concludes that there is no essential change in the leucocytes during starvation, at least in dogs.

Considered numerically both as to total and differential estimations, the following results are reported from studies of fasts in man:

TABLE 11.—*Cetti's and Breithaupt's white-cell count.*
Cetti fasted 11 days, Breithaupt 6.

Day.	Cetti.	Breithaupt.
Before fast.....	Normal.	.....
Fourth day.....	4,800	.....
Sixth day.....	.....	6,500
Ninth day.....	4,200	.....
Broke fast.....	.....	6,870
Second day of diet....	12,300	7,000
Two weeks later.....	7,950	.....

[1]Luciani, Fisiologia del digiuno, Firenze, 1889. Authorized translation by M. O. Fraenkel. Das Hungern, Studien u. Experimente am Menschen, Hamburg u. Leipzig, 1890.

[2]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, **2**, p. 685.

[3]Mühlmann, Russiche Literature über die Pathologie des Hungerns. Centralblatt f. allgem. Path., 1899, **10**, p. 160.

[4]Källmark, Zur Kenntniss des Verhaltens der weissen Blutkörperchen bei Inanition. Folia Hæmat., 1911, **11**, pt. 1, p. 411.

[5]Curtis, Physiology of autonutrition: A study of blood during a prolonged fast. Am. Ass. Adv. Science, 1880, **30**, pp. 95–105.

[6]Hayem, Leçons sur les modifications du sang. Paris, 1882, p. 382.

With both Cetti and Breithaupt[1] a moderate decrease was observed during, with a considerable rise for the first few days following, the fasting period. (See table 11.)

Senator[2] concludes that there is a lively new formation of leucocytes on refeeding.

Luciani[3] records a marked diminution in the early period of Succi's 30-day fast, dropping from 14,536, the count on the first day, to 861 on the seventh. The count then rose to 1,550, where it remained until the twenty-ninth day with slight fluctuations due to concentration and dilution of blood. He attributes the marked diminution to the digestive action of trypsin, which evidently enters the blood as such during the cessation of intestinal digestion. He bases this theory on the work of Albertoni, who by intravenous injection of trypsin got almost a complete disappearance of leucocytes. The trypsin apparently has no effect on the erythrocytes. It is quite possible, also, that there may exist in the early days of the hunger period some special destructive condition, evidenced also by the loss of hæmoglobin. Two other factors at work, he argues, are, first, the disappearance of the lymphocytes, they no longer being required to alter the assimilated products of digestion in the blood plasma (after the work of Schaeffer, Hofmeister and Zawarykins); secondly, the leucocytes may have lost their "Wanderlust." There would, then, not only be a failure of "outwandering" from the blood, but of "inwandering" from the tissues as well, and the latter would exert the greater influence on the number. The white cells practically disappeared from Succi's blood during his fourth fast, till late, when small and ill-formed corpuscles were found.

Tauszk[4] notes a decrease in total count during one of Succi's 30-day fasts. As will be seen in table 12*a* this was due to loss of mononu-

TABLE 12*a*.—*Succi's total and differential white-cell counts.*

Day.	Total white cells.	Polymorphs.	Monocytes.	Eosinophiles.
		p. ct.	*p. ct.*	*p. ct.*
Third.....	9,600	64.1	33.1	2.7
Eighth.....	8,300	....	....	...
Thirteenth...	7,200	....	....	...
Seventeenth..	6,900	68.5	27.4	3.9
Twenty-first.	5,500	....	....	...
Twenty-fifth.	4,800	....	....	...
Thirtieth....	4,200	79.2	16.0	4.7

[1]Lehmann, Mueller, Munk, Senator, and Zuntz, Untersuchungen an zwei hungernden Menschen. Archiv f. path. Anat. u. Physiol., Virchow's, 1893, **131**, supphft., p. 1.

[2]Senator, Bericht über die Ergebnisse des auf Cetti ausgefuhrten Hungersversuchs. Berlin klin. Wochenschr., 1887, **24**, p. 427.

[3]Luciani, Fisiologia del digiuno, Firenze, 1889. Authorized translation by M. O. Fraenkel. Das Hungern, Studien u. Experimente am Menschen, Hamburg u. Leipzig, 1890.

[4]Tauszk, Jahrsb. über d. Fortschr. der Thier-Chemie, 1894, 24, p. 147, abstracted from Orvosi hetilap, Budapest, 1894, p. 512. Also Hæmatologische Untersuchungen am hungernden Menschen. Wien. klin. Rundschau, 1896, **10**, p. 306.

clear cells, including lymphocytes. The eosinophiles and polymorphs were increased. Neubert[1] found the opposite changes, that is, an increase in mononuclear cells and decrease of the eosinophiles and polymorpho-nuclears. His studies were made on cases of carcinoma and pulmonary tuberculosis, so that the inanition was not simple.

There was little change in the white-cell content of Martin's[2] blood during his 9-day fast, except that on the second and ninth days they rose to 10,000. As will be seen in table 12*b*, there was a very slight progressive loss in the polymorphs, while the lymphocytes were increased somewhat on the sixth and ninth days. There was no differential count made to specify the total rise noted on the second day.

TABLE 12*b*.—*Martin's differential white-cell counts.*

Day.	Polymorphs.	Small mononuclears.	Large mononuclears.	Transitionals.	Basophiles.	Eosinophiles.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
Fourth day.....	68	22	6	4	..	..
Sixth day.....	60	30	7	..	..	3
Eighth day.....	55	18	23	..	3	..
Ninth day.....	59	32	9	2	1	..
Sixth day after....	58	35	6	1	..	..

The results of the two examinations of Gayer's[3] blood are given in table 13. The striking points in this case are the very low total count on both occasions, the increase in the small and the drop in the large lymphocytes at the end of the fast. No explanation of these changes is offered by Wile, who made the observations.

TABLE 13.—*Gayer's total and differential white-cell counts.*

Day.	Total white cells.	Polymorphs.	Large lymphocytes.	Small lymphocytes.	Eosinophiles.	Basophiles.
		p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
Eighteenth.....	2,600	54	12.0	30.4	1.6	2.0
Thirtieth.....	2,800	51	5.4	42.0	1.0	.6

In Professor Benedict's subject, whose blood was studied by Dr. Diefendorf,[4] there was evidently normally a high white-cell count. The results are given in table 14.

During the first fast of 7 days there was a progressive diminution till the last day, when there was a slight rise. After an interval of 19 days there was a second fast of 4 days. During this period a gradual rise

[1]Neubert, Ein Beitrag zur Blutuntersuchung, speciell Phthisis pulm. und carcinom, Dorpat, 1889.

[2]Gordon, A prolonged fast. Montreal Med. Journ., 1907, **36**, p. 482.

[3]Gayer's fast: A private communication from Dr. Wile, of New York City.

[4]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 322.

amounting to about 2,000 was noted. The polymorphs averaged high during both fasts, but at no time could the number be considered distinctly pathological. The small lymphocytes averaged low. The large lymphocytes were high during the last 2 days of the first period and throughout the last. The eosinophiles were low and the basophiles high in both fasts.

TABLE 14.—*S. A. B.'s total and differential white-cell counts.*

	Total. white cells.	Polymorphs.	Small lymphocytes.	Large lymphocytes.	Eosinophiles.	Mast cells.
1905.		*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
Prior to fast:						
Mar. 3.....	23,000	....	....	....	....	....
Fasting:						
Mar. 6[1]....	15,750	63	27.0	7.3	2.0	0.6
7.....	13,000	76	15.5	7.3	0.5	.4
8.....	12,000	73	17.5	8.0	1.6	.5
9.....	10,000	76	18.0	5.1	0.4	.6
10.....	10,000	77	10.5	11.5	1.2	.4
	10,000	64	25.0	9.1	1.4	.6
11.....	11,250	75	10.3	12.7	0.45	....
Diet:						
Mar. 12.....	13,250	66	17.5	13.4	1.6	.2
13.....	13,750	66.5	20.5	14.4	0.0	.2
14.....	14,500	69	17.0	10.8	1.65	.2
15.....	15,000	78	14.5	6.9	1.8	.4
20.....	11,750	58.5	22.5	15.7	2.4	1.0
Apr. 3.....	13,000	54	25.0	17.0	1.8	1.0
7.....	13,250	63	14.5	13.9	1.0	1.0
Fasting:						
Apr. 8.....	13.250	69	15.0	12.9	1.3	1.0
9.....	13,250	73	18.3	11.8	1.6	1.0
10.....	13,750	76	21.0	15.4	0.0	.4
11.....	14,500	....	....	....	....	...
Diet:						
Apr. 12....	15,000	68.5	27.3	9.1	0.8	.4
25.....	5,500	62	33.5	3.1	1.6	.4
26.....	8,100	50	35.5	10.9	1.8	1.0
May 5.....	.....	49	45.0	5.8	0.25	...

[1]The first fasting day was March 4–5.

Charteris,[1] in 1907, found a moderate leucocytosis, reaching 14,000 on the sixth day from 5,300, the count before the fast. He noted further a gradual increase of the eosinophiles to 7 per cent, a condition that had never been noted before in human blood during inanition. His subject went 14 days without food, receiving a constant quantity of water, 1 liter per day.

Penny's[2] blood showed also a slight leucocytosis, with a return to normal at the end. Only three counts were made, these with the

[1]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, 2, p. 685.

[2]Penny, Notes on a thirty-day fast. Brit. Med. Journ., 1909, 1, p. 1414.

results shown in table 15. The noteworthy features of the differential counts are the high polymorph percentage, the very marked falling-off of the lymphocytes, and the increase in the large mononuclears.

Reyne[1] could demonstrate no influence on the leucocytes in his dog that fasted for 25 days.

Howe and Hawke[2] studied two men during 7-day fasting periods with uniform water allowance. There was an increase in the polymorphs at the beginning, followed by a decrease to below normal by the end of the fast. The small lymphocytes presented the reverse picture, while the large lymphocytes increased during the early days. One subject showed a moderate increase in eosinophiles. The blood of both men returned to normal after several days of diet.

TABLE 15.—*Penny's total and differential white-cell counts.*

Day.	Total.	Polymorphs.	Large mononuclears.	Lymphocytes.	Eosinophiles.
		p. ct.	*p. ct.*	*p. ct.*	*p. ct.*
Twelfth.....	10,000	76	12	12.0	...
Twentieth....	11,000	76	18	6.0	...
Thirtieth.....	8,800	70	20	7.5	1.5

Even in animals where conditions can be comparatively readily controlled, there has been a striking lack of harmony in the findings. Rabbits and dogs have been the animals of most frequent choice and Okintschitz's[3] report of his work on the leucocytes of the former in 1892 is one of the earliest. He was concerned only with the differential variations. Normally in rabbits the eosinophiles constitute about 50 per cent, lymphocytes 25 per cent, large round cells and polymorphs each 12.5 per cent of the total white-cell content. Following Professor Lukjanow's classification of the inanition period, he divides it into four parts: (1) the stage of indifference; (2) that of excitation; (3) of depression; (4) paralysis of functions. The animals were allowed no water. He found a diminution of the lymphocytes and polymorphs and an increase in eosinophiles and large round cells. During the middle periods, the relative diminution was not so rapid as in the first and last periods. The lymphocytes and mononuclears showed their respective alterations in the first period, while the polymorphs and eosinophiles were not affected till later. The polymorphs showed the most marked diminution and on refeeding they were increased, seeming, therefore, to be the

[1]Reyne, quoted by E. Bardier in his article on Inanition, in Dictionnaire de Physiologie, Charles Richet, 9, p. 99.

[2]Howe and Hawke, Fasting studies, No. IX. On the differential leucocyte count during prolonged fasting. Am. Journ. Physiol., 1912, 30, p. 174.

[3]Okintschitz, Ueber die Zahlenverhältnisse verschiedener Arten weisser Blutkörperchen bei vollständiger Inanition und bei nachträglicher Auffüterung. (Versuche an Kaninchen). Archiv f. exp. Path. u. Pharm., 1892–93, 31, p. 383.

form most affected by food. The disturbance in blood picture was still evident, even when the animals had almost completely regained their body-weight. Hayem,[1] much earlier, in 1882, could see no difference in the variations of the leucocytes in the dog studied by him during its 25-day fast, and those which occur under normal circumstances.

Argaud and Billard[2] found about the same alterations in the blood of the two rabbits they studied, as did Okintschitz. They report a marked hypoleucocytosis with an inversion of the formula, there being present 3 mononuclears to every polymorph. The recovery in these animals, however, was more rapid, for in a few days the blood picture had resumed the normal.

Källmark[3] also studied rabbits during periods of complete starvation varying from 7 to 14 days. He noted a primary fall in lymphocytes and polyneutrophiles, followed by a rise until the seventh day, slow in the latter form, more rapid in the lymphocytes. In the longer fasts this rise was followed by fluctuations, none of which, however, went as high as the normal counts. The basophiles showed a marked rise on the third day of the longer fasts. On refeeding, the polymorphs showed a more rapid rise than the lymphocytes, duplicating the experience of Okintschitz. Källmark concludes that the lymphocytes are supplied in greater abundance during inanition, most probably by the thymus, which in so doing atrophies. The primary fall and the post-inanition rise in the leucocytes occur, he believes, before compensation for the disturbance of equilibrium has been established or the organism has adapted itself to the altered conditions. When this has been accomplished, the changes in the blood are not so much different from those noted under normal circumstances.

Rieder[4] reports finding a marked hypoleucocytosis in the dogs he studied in 1892.

Liuboumdrow[5] found that the leucocytes of his 15 dogs decreased gradually at the beginning of their fasts or until a loss of 20 per cent body-weight was reached. A gradual rise was then noticed, except in 6 of them, frequently reaching normal. The lymphocytes showed a diminution persisting to the end, most marked early, dropping from 15 per cent to 3 per cent or less. The monocytes reappeared to a certain extent, after the primary fall. The polymorphs were proportional throughout to the total count. Eosinophiles appeared early in those animals that did not show them before fasting, and in most cases there was an increase of 7 to 8 times, which lasted until a loss of from

[1]Hayem, Leçons sur les modifications du sang. Paris, 1882, p. 382.

[2]Argaud et Billard, Inversion de la formule leucocytaire sous l'influence de l'inanition. Compt. rend. Soc. Biol., 1911, **70**, p. 746.

[3]Källmark, Zur Kenntniss des Verhaltens der weissen Blutkörperchen bei Inanition. Folia Hæmat., 1911, **11**, pt. 1, p. 411.

[4]Rieder, Beiträge zur Kenntniss der Leukocytose u. s. w., Leipsic., 1892.

[5]Liuboumdrow, Changes in the blood and organs in starvation. 71 Dissert., 1893, Russian. From the Path. Anat. Laboratory, Prof. W. Winogradow, St. Petersburg.

10 to 30 per cent in body-weight had occurred, when they began to diminish. By the end of the fast they had disappeared altogether.

Polétaëw[1] and Reyne[2] both observed great variations in the number of white cells in the dogs they studied, the former concluding that there was evidently a diminution in all the forms until a loss of from 30 to 40 per cent in weight and then an increase toward the end, of the younger elements, including lymphocytes.

Uskow[1] interprets these results as follows: In the beginning the entrance of young leucocytes into the blood is retarded, as is also the transition of the young into ripe forms. In the later period, however, the lymph tissue, probably stimulated into increased activity by the products of degeneration, sends more cells into the blood, and further, there is probably a more rapid development of the young forms already present into ripe cells.

Keuthe[3] noted a decrease in polymorphs and an increase in lymphocytes during the first days and a reversal of this relation in the later days of fasting.

Pashutin,[4] on the other hand, concludes that the fast has practically no effect on the leucocytes, that they show very little alteration.

Howe and Hawke[5] observed the following changes in four dogs receiving only a constant quantity of water: Three of them, fasting 117, 15, and 30 days, respectively, showed a decrease in polymorphs with an increase in the small lymphocytes. The basophiles, eosinophiles, and transitional forms showed no noteworthy changes. The fourth dog, fasting for 48 days, was already anæmic. His blood presented the reverse picture, the polymorphs increased, the lymphocytes decreased. An early-developing eosinophilia disappeared. Two of these four animals showed an increase in large lymphocytes, while the other two showed a fairly constant decrease in the same variety of cell. During later fasting periods of 15 and 30 days in these dogs, the results were quite different, all the forms remaining practically constant, save the large lymphocytes.

The work of Mann and Gage[6] is of interest, though it is concerned with the effects of food rather than of starvation on the morphology and staining properties of the leucocytes. They conclude that during digestion there is a marked increase in the intensity of staining in the nuclei; the

[1]Polétaëw, The morphologic composition of the blood in complete and incomplete starvation in dogs. Dissert. 97, 1894, St. Petersburg (Russian). From the Laboratory of Path. Anat., Prof. Uskow., Riv. internaz. d'ig., Roma, 1895, **6**, p. 129. and Arch. d. sc. Biol., St. Petersburg, 1893, **2**, p. 794.

[2]Reyne, quoted by E. Bardier in his article on Inanition, in Dictionnaire de Physiologie, Charles Richet, **9**, p. 99.

[3]Keuthe, Ueber die funktionelle Bedeutung der Leukocyten im Zirkulierenden Blute bei verschiedener Ernährung. Deutsch. med. Wochenschr., 1907, **33**, p. 588.

[4]Pashutin, Pathological Physiology, Inanition, 1902, **2**, pt. 1, p. 81 (Russian).

[5]Howe and Hawke, Fasting studies, No. IX. On the differential leucocyte count during prolonged fasting. Am. Journ. Physiol., 1912, **30**, p. 174.

[6]Mann and Gage, On the changes induced in blood by feeding, etc. Lancet, Lond., 1912, **2**, p. 1069.

rim of cytoplasm in the lymphocytes becomes narrower; the granules in the leucocytes decrease both in size and number; and the entire cell may show a diminution in size.

Considering again the question of hibernating animals as throwing some light on the changes during simple starvation, the work of Hansemann[1] is interesting. Killing the animals during their hibernating state and examining the various organs, no evidence of cell division could be found. He concludes that the physiologic cell division occurs as a result of the mechanical wearing out of the tissue. If this is eliminated, as it is under these circumstances when muscular and digestive activity and the general vital processes are practically in abeyance, there is no stimulus for cell division. The reduced activity, the absence of intestinal digestive processes or products, and the presence of perverted products of parenteral digestion during fasting, no doubt would be the important factors in influencing the blood picture.

Argaud and Billard[2] examined the blood in hibernating dormice and only a few monocytes were found after careful search, the other forms having apparently disappeared.

Valentin, quoted by Pashutin,[3] had the same experience, finding only a few white cells. He explains their absence to the lack of lymph, which, he claims, introduces the leucocytes into the blood.

Interesting, also, in view of the findings in some of the cases of inanition quoted above, are the changes noted in bone marrow by Roger and Josué.[4] In rabbits that were completely starved for 6 or 7 days the marrow showed the presence of many giant cells. Neutrophilic granular myelocytes predominated, though there were many polymorphonuclear cells. Eosinophilic cells were rare. The fat was largely replaced by a granular, albuminoid substance, not mucin. On refeeding, the eosinophiles were even less in evidence, but there were many very large giant cells and numbers of nucleated red cells, some of them polynuclear. Not before 24 days of feeding did the marrow return to its normal state. This picture is not altogether consistent with the blood findings reported, especially the eosinophilia described by Okintschitz[5] and the scarcity of polymorphs observed by Argaud and Billard.[2]

As already stated, the thymus has been found to atrophy during inanition. Källmark[6] not only noticed diminution in the size of the

[1]Hansemann, Ueber den Einfluss des Winterschlafes auf die Zellteilung. Archiv f. Physiol., 1898, **5** and **6**, p. 262.

[2]Argaud et Billard, Inversion de la formule leucocytaire sous l'influence de l'inanition. Compt. rend. Soc. Biol., 1911, **70**, p. 746.

[3]Pashutin, Pathological Physiology, Inanition, 1902, **2**, pt. 1, p. 81 (Russian).

[4]Roger et Josué, Des modifications histologiques de la moelle osseuse dans l'inanition. Compt. rend. Soc. Biol., 1900, **52**, p. 417.

[5]Okintschitz, Ueber die Zahlenverhältnisse verschiedener Arten weisser Blutkörperchen bei vollständiger Inanition und bei nachträglicher Auffüterung (Versuche an Kaninchen). Archiv f. exp. Path. u. Pharm., 1892–93, **31**, p. 383.

[6]Källmark, Zur Kenntniss des Verhaltens der wiessen Blutkörperchen bei Inanition. Folia Hæmat., 1911, **11**, pt. 1 p. 411.

organ, but in the number of mitotic figures, an evidence of its inactivity. He quotes v. Friedleben as having made the same observations as early as 1859, Hammar in 1905, and v. Jonson in 1909. These are the only references that could be found mentioning the histological appearances of the hæmatopoietic organs during starvation. This is a neglected feature of the subject that would seem to offer a rich field for investigation. Curran[1] and Jolly and Levin[2] write of the general pathological changes. The latter carried out their studies on rats and describe particularly the changes in the lymphatic tissue, essentially, atrophy, particularly of the Malpighian bodies.

PHYSICO-CHEMICAL CHANGES.

Specific gravity.—The question of influence of food and drink and the abstinence from them on the density of the blood has been rather frequently the subject of investigation. We find that, as early as 1834, Thacrah[3] noted an increase in the specific gravity during hunger periods. J. Davy[4] obtained the same result by depriving his subject only of water, and Nasse,[5] starving dogs but allowing water, found that a decrease occurred in specific gravity after 3 to 4 days, but that by the eleventh day the blood had returned to or even exceeded its normal density.

Liuboumdrow,[6] using the pyknometer, detected fluctuations in density as marked, comparatively, as those noted in the number of red cells, but a complete agreement between specific gravity and erythrocyte count was not found.

Castellino,[7] studying starving rabbits, found an increase in density and at the same time a decrease in the serum content of their bloods.

Popel[8] also reports an increase, though a slight one. He studied both rabbits and dogs, using Hammerschlag's method. In the former the increase did not exceed 1.6 per cent and it was still less in the dogs. After ligation of the ureters, there was the slight fall of 9.11 per cent from normal in rabbits, while the dogs showed a rise of 0.72 per cent, a rather unexpected result, if taking only the water content of the blood into consideration.

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[1]Curran, The pathology of starvation, Med. Press and Circ., London, 1880, n. s., **29**, pp. 210 and 229.

[2]Jolly et Levin, Sur les modifications histologiques de la rate à la suite du jeûne. Compt. rend. Soc. Biol. Paris, 1912, **72**, p. 829.

[3]Thacrah, An inquiry into the nature and properties of the blood as existent in health and disease. London, 1819–1834.

[4]Davy, Physiolog. and Anat. Researches. London, 1839.

[5]de Martigny u. Nasse, Ueber den Einfluss der Nahrung auf das Blut. Marburg u. Leipsic., 1850.

[6]Liuboumdrow, Changes in the blood and organs in starvation. 71 Dissert., 1893, Russian. From the Path. Anat. Laboratory, Prof. W. Winogradow, St. Petersburg.

[7]Castellino, La Suscettibilitá infettiva nella inanizione lenta. Riv. d'Igiene e Sanita Pub., Roma, 1893, 4, No. 3, p. 461.

[8]Popel, Sur les variations de la densité du sang dans le jeûne absolu, simple, ou compliqué de la ligature des urêtères. From the Laboratory of General Pathology, Prof. S. Lukjanow, Arch. des sci. Biol., 1895–96, 4, p. 354.

London's[1] findings do not agree with those above. He also used Hammerschlag's method, but reports a slight diminution in the rabbits that starved for from 5 to 14 days, the average dropping from 1.048 to 1.043. The animals in both the above series were deprived of water.

There was evidently a considerable fall in Martin's[2] blood, for while no preliminary estimation was made, on the sixth day of his fast the specific gravity was 1.026; on the eighth it rose to 1.031, and on the ninth and last day it had dropped to 1.021. One week after breaking fast it was 1.043, still very low if we consider the normal to be 1.059 to 1.060.

Lloyd Jones is quoted by Lyonnet[3] as finding, on the tenth day of one of Succi's fasts, a specific gravity of 1.061 that rose to 1.063 on the thirty-ninth day. In speaking of the influence of food and drink on the specific gravity, Lyonnet holds that there is usually, though not invariably, a diminution after the intake of water, the change being but very temporary. Abstinence from all liquid causes an increase, but not of so marked a degree as one would suppose. (In this he is quoting Lichtheim.) Food apparently has some effect, in that after meals there is a decrease to be found that lasts for an hour or so.

Coagulability.—Very little mention is made in the literature of the influence of inanition on the coagulation time. Vierordt[4] was among the first to refer to this feature of the subject, having made the observation, in 1878, that an acceleration of the process occurred as a result of starving.

Arnold[5] and Collard de Martigny[5,6] both noticed that the clot was larger than usual in relation to the amount of serum, and the latter in 1850 found a decrease in fibrin content.

Jones[5] also noted that the water and fibrin decreased more rapidly than the solid constituents.

Källmark[7] noticed that in rabbits, after the fifth or sixth day of starvation, the blood coagulated more rapidly, but no estimations of the time are given.

Tria[8] reports quite recently that he could detect very little variation during short fasts in rabbits and dogs.

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[1]London, Note sur la question du changement de la quantité generalé et de l'alcalinité du sang dans le jeûne absolu. Arch. des Sciences Biol., 1895–96, **4**, p. 516. (Abstract by Mühlmann. See footnote 5, this page.)

[2]Gordon, A prolonged fast. Montreal Med. Journ., 1907, **36**, p. 482.

[3]Lyonnet, De la densité du sang, sa détermination clinique, ses variations physiologiques et pathologiques. Paris, 1892, p. 73.

[4]Vierordt, Arch. d. Heilk., 1878, **14**, p. 193.

[5]Mühlmann, Russisch Literatur über die Pathologie des Hungerns. Centralblatt f. allgem. Path., 1899, **10**, p. 160.

[6]de Martigny u. Nasse, Ueber den Einfluss der Nahrung auf das Blut. Marburg u. Leipsic., 1850.

[7]Källmark, Zur Kenntniss des Verhaltens der weissen Blutkörperchen bei Inanition. Folia Hæmat., 1911, **11**, pt. 1, p. 411.

[8]Tria, Propriétés chimico-physiques du sang durant l'inanition. Archiv. ital. de biol., Pise, 1911, **55**, p. 49. (Arch. di farmacol. sper., Roma, 1909, **8**, p. 359.)

Valentin[1] noticed a marked retardation of coagulation in hibernating animals.

No report of the specific estimation of coagulation time during fasting in man could be found. Dr. Wile[2] reports that on both examinations of Gayer's blood, made on the eighteenth and thirtieth days, there was apparent decrease in the platelets, but that coagulation was accelerated. He says, of the last examination, that "the blood was thick, dark red, and did not flow easily." Aside from such general conclusions without data to demonstrate them, the only clue as to what might be expected in man are a few observations that have been made relative to meal times.

Coleman[3] found the longest coagulation time an hour after the principal meal and the shortest before breakfast.

Cohen,[4] using the method devised by himself, determined that the average time before meals was $7\frac{1}{6}$ minutes and after meals 9 minutes, while Mercier, quoted by Cohen in the above article, constantly found the coagulation more rapid after meals than before, and Addis[5] claims that food has no influence on the process.

Cohen[4] quotes A. E. Wright as crediting fluids with a greater influence on coagulability of the blood than food, but that hunger does retard the process, a view not upheld by the observations of Coleman and Cohen. Increased consumption of liquids lengthens the time and withholding them has the opposite effect.

Immunity.—There have been a few studies made of the effect of starvation on immunity in general and the immune body-content of the blood specifically, but the data are scarcely sufficient to warrant definite conclusions.

In 1890 Canalis and Morpurgo[6] studied the effect on the natural immunity pigeons exhibit toward anthrax. They were found constantly to lose this resistance if the fast were begun immediately after the injection of the organisms, or a day or so before. They regained it, however, on refeeding, if the inanition period had not been too long. This same natural immunity possessed by chickens[7] was not lost unless they were starved for more than 8 days. If starved before inoculation they proved more susceptible. These workers were unable to make rats susceptible to anthrax by starving.

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[1]Valentin, Repel. f. Anat. u. Physiol., 1838, 3, p. 156.

[2]Gayer's fast: A private communication from Dr. Wile, of New York City.

[3]Coleman, The coagulation of the blood and the effects of certain drugs upon it. Biochem. Journ., 1906–7, 2, p. 184.

[4]Cohen, Coagulation time of the blood as affected by various conditions. Arch. Int. Med., 1911, 8, pp. 684 and 820.

[5]Addis, The coagulation time of the blood in man. Quart. Journ. Exp. Physiol., 1908, 1, p. 305.

[6]Canalis and Morpurgo, Ueber den Einfluss des Hungers auf die Empfänglichkeit für Infectionskrankheiten. Fortschr. der Medicin, 1890, 8, p. 693.

[7]Canalis and Morpurgo, *ibid.*, 8, p. 729.

P. Castellino[1] concluded, from his studies on rabbits in 1893, that there was a diminution in resistance to infection.

A few years later, in 1899, Meltzer and Norris[2] could demonstrate no difference in the bactericidal action against the typhoid bacillus of the blood of starved, under- or overfed dogs.

Roger and Josué,[3] on the other hand, having observed an increase in the resistance to the colon bacillus in fasting rabbits, suggest that some possible benefit may be derived from fasts. This is the only bit of experimental evidence—with reference to the blood, at least—that speaks for the value or advisability of this procedure as a general therapeutic measure. This increase in resistance they attribute to hyperactivity of the bone marrow, whereby there is a more rapid proliferation of the defensive cells.

Charteris[4] noticed a wide daily variation in the opsonic index of the blood of his human subject during the latter's 14-day fast, but, as he obtained a similar result with his own blood, he was led to conclude that the changes during fasting were not significant, due, rather, to the use each day of a fresh emulsion of bacteria. Martin's[5] blood, however, showed a gradual lowering of the index, returning to normal 4 days after the fast was broken. In this case the *Staphylococcus aureus* was used.

Bizzozero[6] studied the natural hæmolytic power of the blood serum of 8 chickens that starved for from 8 to 17 days and could find practically no alteration. He concludes that the hæmolysins are not concerned in the defense of the organism against bacterial invasion, because, as we have seen from the work of Canalis and Morpurgo, starving does lower the resistance to infection.

Among the studies on other properties of the blood are to be mentioned those of Tria,[7] on the viscosity and electro-conductivity in rabbits and dogs. He found little alteration, some decrease, in both early. He concludes from his entire study that the body is able to compensate pretty well for the disturbances in nutrition, thus permitting of long fasts without serious consequences. The investigations of Determann,[8] and of Marañón and Saristán[9] dealt especially with the viscosity.

[1]Castellino, La Suscettibilitá infettiva nella inanizione lenta. Riv. d'Igiene e Sanita Pub., Roma, 1893, **4**, No. 3, p. 461.

[2]Meltzer and Norris, On the influence of fasting upon the bactericidal action of the blood. Journ. Exp. Med., 1899, **4**, p. 131.

[3]Roger et Josué, Influence de l'inanition sur la resistance à l'infection colibacillaire. Compt. rend. Soc. Biol., 1900, **52**, p. 696.

[4]Charteris, Record of changes observed in the blood count and in the opsonic power of a man undergoing a prolonged fast. Lancet, 1907, **2**, p. 685.

[5]Gordon, A prolonged fast. Montreal Med. Journ., 1907, **36**, p. 482.

[6]Bizzozero, Pouvoir hémolytique naturel, pulet dans l'inanition aigué. Arch. ital. de biol., Turin, 1904–5, **42**, p. 212.

[7]Tria, Propriétés chimico-physiques du sang durant l'inanition. Archiv. ital. de biol., Pise, 1911, **55**, p. 49. (Archiv. di farmacol. sper., Roma, 1909, **8**, p. 359.)

[8]Determann, Die Beziehung der Viskosität des Blutes zu den Körperfunktionen. Veröffentl. d. balneol. Gesellsch. in Berl., Berlin u. Wien, 1910, pp. 259 and 270.

[9]Marañón y Saristán, La viscosidad de la sangre humana en varios estados patalógicos. Rev. Ibero Am. de cien. méd., Madrid, 1911, **26**, p. 244.

A decrease in alkalescence was noticed by Tauszk[1] in Succi's blood, by Castellino[2] in rabbits, and Benedict reports the same change in his subject.[3] A very moderate decrease was also observed by London[4] in his eight rabbits. Castellino[2] found also a decrease in NaCl content and in the bulk of serum.

For additional data as to the effects of inanition on the physico-chemical properties, reference can be made to the work of Githens,[5] Schœneich,[6] Fria,[7] Lattes,[8] Robertson,[9] Bierry and Fandard,[10] Daddi,[11] Morozoff,[12] and Weber[13] (who includes an exhaustive correlation of references to the literature of the entire subject of inanition). Manca[14] and Macalum[15] confined their investigations to the cold-blooded animals.

OBSERVATIONS ON L.'S BLOOD.

There is little danger of one's opinions being biased by the diverse results above correlated. We can therefore take up the consideration of our subject's blood either with an open mind free from preconceived ideas, or with confused expectations, ranging from absolutely negative findings to very grave disturbances, with the confidence that we have precedent for almost any picture that may present itself. The coagulation time and specific gravity were investigated, but the examinations were concerned principally with the red and white cell and hæmoglobin content, the technique for which follows. That employed in the

[1]Tauszk, Jahrsb. über d. Fortschr. der Thier-Chemie, 1894, **24**, p. 147, abstracted from Orvosi hetilap, Budapest, 1894, p. 512: also Hämatologische Untersuchungen am hungernden Menschen. Wien. klin. Rundschau, 1896, **10**, p. 306.

[2]Castellino, La suscettibilitá infettiva nella inanizione lenta. Riv. d'Igiene e Sanita Pub., Roma, 1893, **4**, No. 3, p. 461.

[3]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 322.

[4]London, Note sur la question du changement de la quantité générale et de l'alcalanité du sang dans le jeûne absolu. Arch. des Sciences Biol., 1895–96, **4**, p. 516. (Abstract by Mühlmann. See footnote 5, p. 145.)

[5]Githens, Influence of hunger and hæmorrhage on the composition of the blood plasma. Proc. Phila. Count. Med. Soc., Philadelphia, 1904–5, **25**, p. 279.

[6]Schœneich, Beschaffenheit des Blutes unter verschiedenen Bedingungen. Ztschr. f. exp. Path. u. Therap., 1905, **2**, p. 419.

[7]Fria, Alcune ricerche comparative sul sangue di animali nutriti naturalmente ed innaturalmente. Folia clin., chim. et micros., Salsomaggiore, 1910–11, **3**, p. 44.

[8]Lattes, Ueber den Fettgehalt des Blutes des Hundes unter normalen u. unter verschiedenen experimentellen Verhältnissen (Verdauung, Hungern, etc.). Arch. f. exp. Path. u. Pharmacol., Leipzig, 1911, **66**, p. 132.

[9]Robertson, Studies in the blood relationship of animals, etc. 1. A comparison of the sera of the horse, rabbit, rat, and ox with respect to their content of various proteins in the normal and in the fasting condition. Journ. Biol. Chem., Baltimore, 1912, **13**, p. 325.

[10]Bierry et Fandard, Variations de la glycémie pendant l'inanition. Compt. rend. Acad. d. sc., Paris, 1913, **156**, p. 2010.

[11]Daddi, Sur les modifications du poids de l'extrait éthéré du sang durant le jeûne de longue durée. Arch. ital. de Biol., Turin, 1898, **30**, p. 439; also Sulle modificazioni del peso dell estratto estereo del sangue durante il digiuno di lunga durata. (Sperimental.) Arch. di biol., Firenze, 1898, **52**, p. 43.

[12]Morozoff, On the effect of fasting for a short time on the morphologic composition of the blood. (Russian) Vrach. St. Petersburg, 1897, **18**, p. 1081.

[13]Weber, Ueber Hungerstoffwechsel. Ergebnisse der Physiologie (Biochemie), 1902, 1 Abt., p. 702.

[14]Manca, Le cours de l'inanition chez les animaux à sang froid. Arch. ital. de biol., Turin, 1895, **23**, p. 243, and 1896, **25**, p. 299; also Chemical researches on animals (cold-blooded) during inanition (Italian). Arch. ital. de biol., Turin, 1903, **39**, p. 193.

[15]Macalum, The inorganic composition of blood plasma in the frog after a long period of inanition. Rep. Brit. Assoc. Adv. Sc., London, 1911, **80**, p. 766.

coagulation and specific-gravity estimations is given under these headings. The attempt was made to determine the opsonic index, but the subject was so far from an incubator and centrifuge that it was found impossible to obtain accurate results. There was a possibility, also, of this additional manipulation having a disturbing influence on the physiological investigations, so this feature was abandoned, though still recognized as one of the most important lessons to be learned from the blood.

Technique.—For the three days just preceding the fast, Levanzin's blood was examined to determine a normal picture with which to compare the results later obtained. During the fast, with the exception of the first day and three days scattered through the period, daily examinations were made and also on the first and third days of refeeding. The time of the day did not vary more than half an hour throughout, all the specimens being obtained between 10 and $10^h\ 30^m$ a. m., so that there was a constant relation to the general routine of the subject's daily activities—that is, immediately after he had finished with the respiration experiment, had been weighed, had washed his face and hands, and climbed the short flight of stairs to his balcony. It was his habit to take about half a glass of water before submitting to the lancet prick. (It may be well to mention here that, for the first 10 days of the experiment, the subject received the constant quantity of 750 c.c. of distilled water per day, and thereafter, 900 c.c. per day.) The specimens of blood were obtained from alternate fingers of the left hand and occasionally from the ear. Deep pricks were made, so as to obtain sufficient blood without squeezing. For counting the red and white cells the Thoma-Zeiss apparatus was used, diluting with fresh salt solution for the former and 1 per cent acetic-acid solution tinged with gentian-violet for the leucocytes. The usual precautions were taken to insure uniform suspension of corpuscles and the even filling of the counting chamber. In the case of the erythrocytes, 80 small squares were counted and 4 ciphers added to the total. The average of two or more such figures was taken as the final result. In estimating the leucocytes, the whole cross-ruled field was counted and the result multiplied by 200. The average of three or more such figures was taken as the final estimation. The use of gentian-violet in the acetic-acid solution makes the counting of the leucocytes much easier and the likelihood of mistaking foreign particles for cells practically impossible. The smears for the differential counts were stained by the Wright method; 200 or more cells were examined by the use of the $\frac{1}{12}$ objective and No. 1 eye-piece, and classified as follows: Polymorphonuclear neutrophile, eosinophile, and basophile; small and large lymphocyte; monocyte; transitional cell. As the classification of the last three forms is so mooted a question, it will be necessary to go into some detail as to just what cells were placed under these heads.

Under large lymphocyte was classified the mononuclear cell, considerably larger than the red corpuscle, with a round or typically

indented nucleus (like that of the small lymphocyte though not staining as deeply), small amount of cytoplasm in proportion to nucleus, the former not being markedly basophilic and usually containing a few faintly-staining granules. The mononuclear was considered the cell whose nucleus was more indented, the proportion of cytoplasm was greater and granules more evident, the latter basophilic and the whole cell staining more deeply than the large lymphocyte. The occasional large mononuclear cell of the endothelial type was also counted in with these cells, though not considered as being associated with them generically. The transitional cell showed a pale-staining, usually kidney or horse-shoe shaped nucleus, surrounded by cytoplasm, pale and free from granules. This classification follows generally that of Pappenheim.[1]

In estimating the hæmoglobin percentage the Tallqvist[2] scale was used throughout the series. This method, it is true, is open to some criticism in that it is scarcely possible to detect differences of less than 3 per cent. My experiences, however, have developed a confidence in it that has been justified by comparative readings with other methods. In the present case, from the nineteenth to the twenty-fourth day, estimations were made with the Sahli apparatus and the results were practically the same as those obtained for the same days with the Tallqvist scale. Care must be taken to follow exactly the same technique for each reading, particularly in the matter of light; the results will then be relatively correct, even if the method is comparatively weaker than some of the others.

The results of these examinations are contained in table 16. They are correlated and presented more graphically by curves given in figures 20 and 21. No. I shows the relation of hæmoglobin to red cells, and No. III the relation of the total white-cell count to the differential. To avoid confusion of curves the transitional, eosinophile, and basophile are plotted separately in No. IV and the scale enlarged. In No. II the composite curve of the polynuclears, that is, neutrophiles, basophiles, and eosinophiles and one of the mononuclear cells, large and small lymphocytes, transitionals, and monocytes, are given for comparison.

Erythrocytes.—The subject's normal count apparently was high; the three preliminary estimates range well above 6,000,000. It maintained this high figure throughout the test, going below it on only two occasions, the tenth day of the fast and the third day following. In the early part of the fast there is daily variation, ranging under 1,000,000. This becomes less evident toward the end. The general impression given by the curve is that of a very moderate decrease. There were no alterations in the characteristies of the individual cells as to size, shape, and staining properties and no nucleated red cells were found at any time.

[1]Pappenheim u. Ferrata, Ueber die verschiedenen lymphoiden Zellformen des normalen und pathologischen Blutes. Folia Hæmat., 1910, **10**, p. 78.

[2]Tallqvist, Ueber die Anwendung des Filtrirpapiers in Dienst der praktischen Hæmatologie, Berl. klin. Wochenschr., 1904, **41**, p. 926.

Hæmoglobin.—The hæmoglobin average ranges rather consistently above 85 per cent, the most marked variations being consistent with those of the erythrocytes. The low period is between the tenth and sixteenth days, from then on showing a very moderate rise.

TABLE 16.—*Levanzin's cell counts and hæmoglobin percentage.*

Days.	Hæmoglobin.	Total erythrocytes.	Total leucocytes.	Polymorphic neutrophiles.	Small lymphocytes.	Large lymphocytes.	Monocytes.	Transitionals.	Eosinophiles.	Basophiles.
Days before fasting:	*p. ct.*			*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
3d	85	8,984,000	5,900	67.5	23.5	2.5	4.5	1.5	0.5	0
2d	85	6,632,000	5,400	66.0	22.0	1.5	7.5	2.0	.5	.5
1st	95	7,000,000	6,000	59.5	32.0	3.0	4.0	0	1.5	0
Days of fasting:										
2d	90	6,100,000	8,400	73.0	20.0	3.0	3.0	.5	. 5	0
3d	92	7,200,000	12,400	79.0	16.5	.5	3.0	.5	.5	0
4th	92	6,120,000	8,400	66.0	24.0	4.0	4.0	1.0	.5	0
5th	91	7,170,000	9,400	68.0	26.5	2.0	3.0	.5	0	0
6th	90	6,250,000	8,600	67.5	19.0	4.5	3.0	5.0	.5	.5
7th	88	6,450,000	7,000	60.0	24.0	4.0	3.5	6.5	2.0	0
9th	90	7,000,000	8,500	66.0	26.0	3.5	1.0	3.0	.5	0
10th	88	5,950,000	7,000	68.0	22.0	3.0	3.0	1.5	1.0	.5
11th	85	6,750,000	8,400	68.0	23.0	2.0	5.0	2.0	0	0
12th	85	6,480,000	7,000	74.0	15.0	2.0	4.5	3.0	1.5	0
13th	85	6,580,000	6,800	64.0	24.5	7.5	1.0	2.0	.5	.5
14th	87	6,280,000	7,900	64.0	26.5	4.0	2.5	2.5	.5	0
16th	85	6,010,000	9,000	72.5	16.5	3.5	1.5	5.0	.5	.5
17th	88	6,600,000	6,200	64.5	29.0	3.0	.5	3.0	0	0
18th	88	6,700,000	6,600	65.5	24.0	6.5	2.0	1.0	1.0	0
19th	88	6,250,000	6,200	62.5	22.5	5.5	3.5	5.0	.5	.5
20th	88	6,250,000	6,400	61.0	28.5	3.0	3.5	2.5	1.0	.5
21st	87	6,450,000	6,400	62.5	20.5	5.0	5.5	5.5	1.5	0
22d	88	6,130,000	6,100	61.0	26.5	3.5	6.5	2.5	0	0
23d	90	6,630,000	6,600	58.5	28.0	4.5	4.5	3.0	.5	1.0
24th	88	6,000,000	6,900	65.0	25.0	2.5	4.5	2.5	.5	0
25th	87	6,250,000	6,500	65.5	27.0	1.5	5.0	1.0	0	0
27th	90	6,240,000	5,800	63.0	26.0	3.0	6.5	1.5	0	0
28th	..	6,350,000	7,800	61.5	30.0	1.0	5.5	2.0	0	0
29th	90	6,190,000	6,000	63.5	27.5	1.5	5.0	2.0	0	.5
30th	92	6,050,000	6,000	64.5	26.5	2.0	5.0	1.5	.5	0
31st	93	6,170,000	8,000	60.0	32.0	2.5	5.0	.5	0	0
Days of diet:										
1st	92	6,280,000	7,200	70.0	21.5	2.5	4.5	1.5	0	0
2d	.....	Too ill for examination.								
3d	92	5,960,000	6,600	60.5	32.5	3.0	3.0	0	.5	0

Leucocytes.—It is in the total leucocyte count that we have the most striking change of the whole series of examinations. There was a rapid rise at the onset of the fast, reaching 12,400 on the third day. On the fourth day, however, it immediately fell to 8,400, after which there was a consistent daily variation of about 1,000 until the sixteenth day, when it reached approximately the preliminary count, after which there will be noticed a more marked daily variation. It was only possible to continue the examinations for 3 days following the fasting period, so that the count had not settled down to normal when the subject went out from under observation.

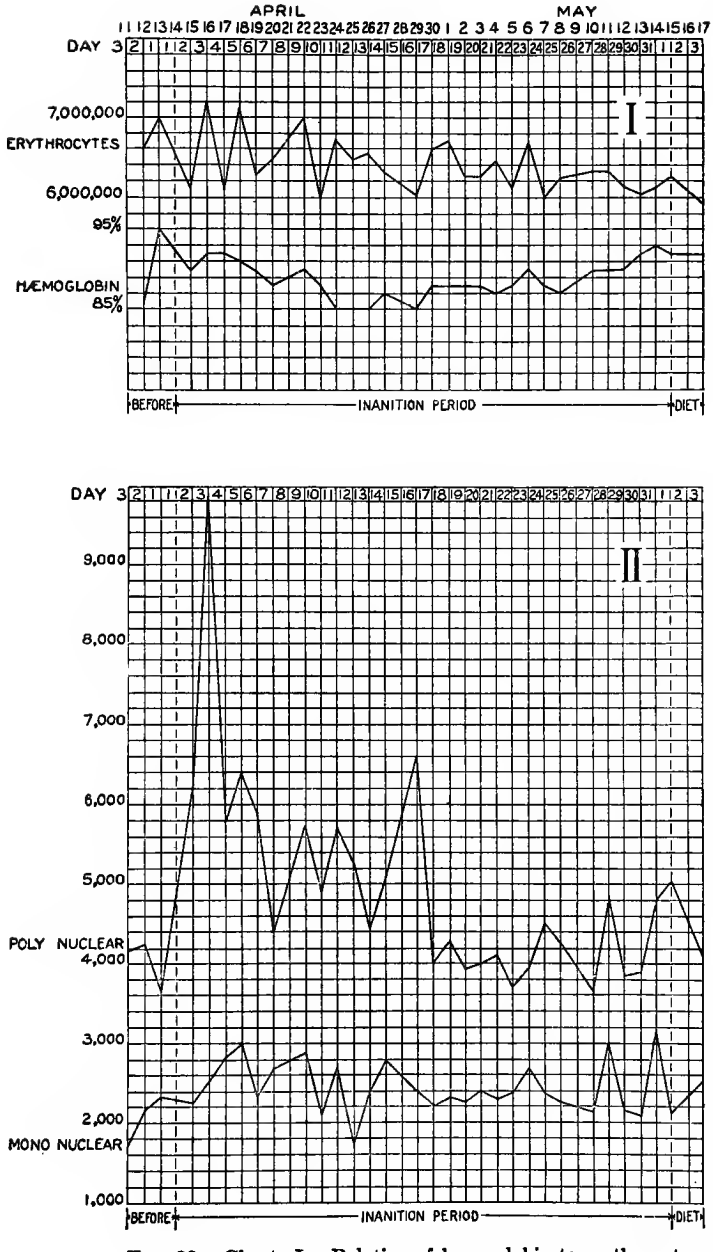

FIG. 20.—Chart I. Relation of hæmoglobin to erythrocytes.
Chart II. Composite curve of the polynuclears compared with one of mononuclears.

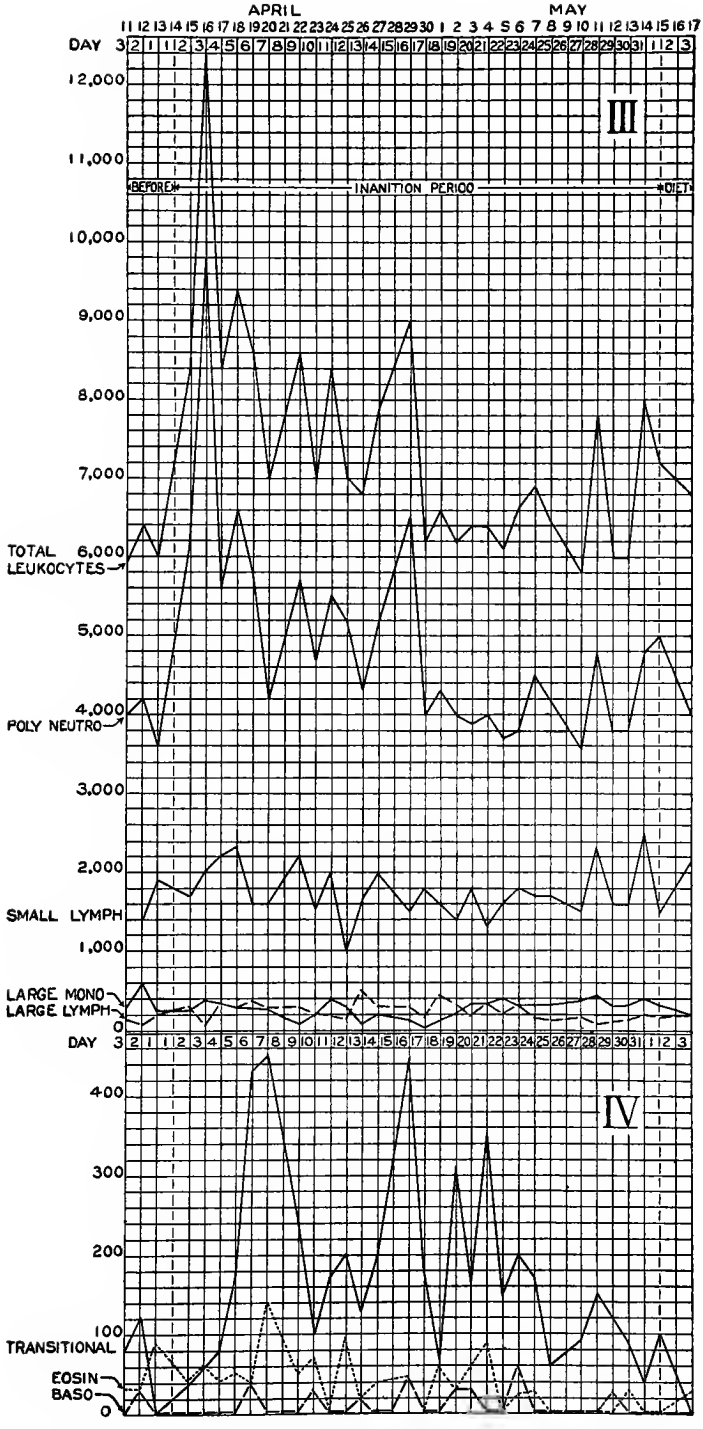

FIG. 21.—Charts III and IV. Relation of total to differential leucocyte counts.

Polymorphonuclear neutrophiles.—These ran throughout rather consistently with the total count and the marked variations in this latter were quite apparently due to the change in polynuclear content.

Small lymphocytes.—There are fluctuations in the count of this cell, except during the period between the fourteenth and twenty-seventh days, when they were comparatively constant, as were also the total and polymorpho-neutrophile counts. It will be noted that the majority of the rises and falls are the opposite of those seen in total and polymorpho-neutrophile curves. This is particularly the case on the second, fourth, thirteenth, fourteenth, sixteenth, seventeenth, twentieth, and twenty-first days of fast and the first day of refeeding. It seems safe to conclude, therefore, that these fluctuations are only relative, due really to the fluctuations in polymorphs, and that their number was practically constant throughout the fast.

The other forms of leucocytes present no distinctive features except the transitional, which was subject to several rises, namely, on the seventh, sixteenth, nineteenth, and twenty-first days, when they were above 5 per cent. Only an occasional eosinophile was found during the last 10 days of the fast and they had not returned to their usual number when examinations were discontinued. By examination of chart No. II (figure 20), there appears to be a very slight increase in the combined mononuclear cells throughout the fasting period, the average being raised by the fluctuations in the transitional form, for the other types, *i. e.*, monocyte, large and small lymphocyte are practically constant throughout, except the variations already noted in the latter.

Coagulation time.—Toward the end of the second week of inanition it was noticed that the blood coagulated more rapidly than it had during the earlier days. This became more noticeable each day, so that if the mixing pipettes were not filled very rapidly the drop would coagulate or the blood would clot in the tubes. It is certain that this was not due to any physical alteration of the patient's environment. The temperature of the balcony where the subject stayed and where the estimations were made was practically constant. This is a very important factor, for most experimental evidence goes to show that variations in temperature have decided influences on the coagulation time. Addis, Fox, and Wright, quoted by Cohen,[1] and the latter himself, all showed that rise in temperature accelerates and cold retards the process. Hartmann[2] also notes that the higher the temperature the shorter the coagulation time, and Rudolf,[3] determining the effect more specifically, states that in general each degree of rise and fall between 15° and 20° C. decreased and increased, respectively, the time one minute.

On the seventeenth day the estimations of the coagulation time were begun. Until the twenty-fifth day the McGowan[4] method was used.

[1]Cohen, Coagulation time of the blood as affected by various conditions. Arch. Int. Med., 1911, **8**, pp. 684 and 820.

[2]Hartmann, Zur Frage der Blutgerinnungszeit. Münch. med. Wochenschr., 1909, **56**, p. 796.

[3]Rudolf, Tr. Assoc. Am. Phys., Philadelphia, 1910, **25**, p. 504.

[4]McGowan, A clinical method for estimating the coagulation time of the blood. Brit. Med. Journ., 1907, **2**, p. 1580.

Capillary tubes of uniform caliber were filled with blood escaping after the specimens for the other examinations had been obtained, practically always the same relative drop, the third. Small sections were broken off at intervals of from 10 to 30 seconds. When a fine filament of fibrin was observed between the carefully separated ends of the tube and fragment, the time elapsed since the appearance of the drop used was taken as the reading. For the remainder of the examinations, the Boggs[1] apparatus was used. This consists of a truncated cone of glass that sets into a chamber into the side of which a small metal tube is inserted, connected with a rubber bulb, in such a way that a stream of air can be directed against the blood that is placed on the polished undersurface of the cone. As soon as coagulation has occurred in the drop, the mass of corpuscles that moved readily in one direction under agitation of the air-current merely vacillate. This method is more accurate than the first procedure, but is open, as are all the other devices for measuring coagulation time, to sources of error that, if not avoided, will cause wide variations in results. This refers particularly to the matter of temperature, the particular drop used, and the presence of foreign particles in the blood or on the receiving surface of the cone, such as hair or lint. The first drop appearing after the prick will clot much slower than the subsequent ones, when the platelets will have accumulated about the edge of the wound. It is necessary, therefore, to use the same relative drop on each examination, preferably the second, though, as has been stated, in this case the third was used.

TABLE 17.—*Coagulation times of Levanzin and a control.*

Day.	Levanzin.	J. F.	Remarks.
17th.....	1′ 5″	0′ 3″	McGowan method.
18th.....	1 20	2 50	Do.
19th.....	1 20	2 00	Do.
20th.....	1 5	.. ..	Do.
21st.....	0 55	1 55	Do.
22d.....	1 20	.. ..	Do.
23d.....	1 5	1 35	Do.
24th.....	1 5	4 20	Boggs used on control.
25th.....	.. ..	4 50	From this day on, Boggs
27th.....	3 20	4 +	used on both.
28th.....	2 50	.. ..	
29th.....	2 20	.. ..	
30th.....	1 50	3 30	
31st.....	2 30	.. ..	
First diet....	2 45	6 20	

Note: ′=minutes; ″=seconds.

The figures as obtained by these two methods, together with those found in a normal individual examined on the same days with the same methods and under approximately the same conditions, are collected in table 17. The last record on the control was made in a temperature at

[1]Boggs, Johns Hopkins Hosp. Bull., Baltimore, 1904, **15**, p. 174.

most 2° C. cooler than that of the subject's environment, but a deduction of 2 minutes, as correction for this, still leaves the time distinctly longer than that obtained on the same day in Levanzin's blood. A comparison of the two series of results will demonstrate a distinct increase in the coagulability of the starving man's blood, more noticeable toward the end of his fast.

Specific gravity.—The specific gravity was determined only twice, while the subject was eating his first meal after fasting and on the third day of refeeding. The first time it was 1.0612, the second it was 1.0618. The estimations were made by the Hammerschlag[1] method, the specific gravity of the mixture of chloroform and benzol being determined by the pyknometer. As no figures were obtained, either before or during the fast, these two examinations are of little value, except that from them it may be assumed there is a very slight increase in density, taking 1.059 to 1.060 as the average normal specific gravity.

DISCUSSION AND CONCLUSIONS.

The results of the above studies are conspicuous rather from the absence than the presence of striking alterations in the blood picture. Really the only prominent features are the early rise in polymorphonuclear neutrophiles and the decrease in coagulation time. The leucocytes, *i. e.*, the neutrophiles, at least, are the most sensitive of the blood-cells to changes in body conditions, and we know that apparently slight disturbances will call forth a recognizable increase in these cells—a cold bath, for example. They seem always to be on the alert, ready at the least evidence of disturbance to rush forth in defense of the organism. It is scarcely to be wondered at, therefore, that in response to such an unusual condition as starvation there should be an outpouring of the reserve supply, at least for a day or so, or until the organism has had an opportunity to adapt itself to the altered conditions. The variations in water-content of the blood can not be considered a factor in this rise, involving as this does only the one form of cell. The only explanation that suggests itself, therefore, and frankly not a particularly scientific one, is this alertness of the polymorpho-neutrophile and its ever-readiness to be on the defense for the organism. The products of the somewhat perverted metabolism may excite them into this early activity and later fail to do so, but there is no evidence to prove this supposition. It is not easy to understand why they should respond to toxic products in the early days and not during the later as well, unless we assume they acquire a tolerance for them, which seems improbable when we compare the reaction to infections, in which their fight is evident throughout the disease if the organism is to conquer. It is further possible that an insignificant, obscure source of bacterial infection happened to develop at this particular time; if so, there was no other evidence.

[1]Hammerschlag, Wien. klin. Wochenschr., 1890, 3, p. 1018.

As to the effect of the starving on the total quantity of blood, it does seem evident that there are fluctuations, at least in the first two weeks. By comparing the curves of the white- and red-cell counts it will be noted that the variations are synchronous; that on the third, fifth, ninth, and eleventh days particularly the noticeable increases in the one are accompanied by equally frank rises in the other. It would seem that this could only be due to variations in water-content. The specific gravity would have gone far toward proving this point, but unfortunately this was not determined during this period. Taking these fluctuations as indication of variations in water-content, it appears that during the middle period of the fast, at least, the equilibrium of intake (including that drawn from tissues) and output was pretty well established. The last counts made, namely, on the third day after the fast was broken, are considerably lower than those of the last day of fast. This no doubt is a relative decrease, due to increase in water-content. While the diet was of course limited, there was an increase in the intake of fluids.

The hæmoglobin appears to be particularly resistant, the percentage on the last day being within 2 per cent of the highest estimation, found on the day before fast began, though there was a moderate decrease during the second 10 days.

It is difficult to account for the only other marked change in the blood—the acceleration of coagulation. Loss of water could be responsible, but there is no evidence that this occurred. The very slight increase in density at the last, determined by the specific gravity, would certainly not demonstrate a sufficient concentration. There were no estimations of the platelet content made, but it is possible that the explanation lies with these. An increase in them could be responsible.

The final conclusions as to the effects of uncomplicated starvation on the blood to be drawn from the results of examinations on Levanzin are:

1. There is a slight actual loss in hæmoglobin, more marked during the second 10 days.

2. There are moderate fluctuations in water-content, particularly during the first half of the period, and an increase after breaking fast, evident till after the third day, at least.

3. There is a decided rise in polymorpho-neutrophiles in the early days.

4. There is an increase in coagulability, especially after the first two weeks.

5. In an otherwise normal individual, whose mental and physical activities are restricted, the blood as a whole is able to withstand the effects of complete abstinence from food for a period of at least 31 days, without displaying any essentially pathological change.

MECHANICS OF RESPIRATION.

A physiological study of the human body during a prolonged fast would be incomplete without a careful investigation of the influence of inanition upon the mechanics of respiration. Fortunately, it was possible to obtain such data in all of the experiments with the respiration apparatus, as the spirometer gave a graphic record of the respiration,[1] from which accurate data regarding the respiration-rate, the ventilation of the lungs per minute, and the volume of air per inspiration could be obtained. Such data are available for the morning respiration experiment for every day of the fast, for the experiments made in the evening before the subject entered the bed calorimeter, for experiments made on several occasions when the subject was sitting quietly or sitting writing, and also for experiments in which he breathed an oxygen-rich atmosphere.

TYPICAL GRAPHIC RECORDS OF RESPIRATION.

The graphic records obtained by the spirometer method have a special interest in connection with the fasting experiment in that they indicate the character and rate of the respiration as the fast progressed. Out of 200 or more records obtained with this subject, four typical curves have been selected for reproduction in figure 22, *i. e.*, one each for April 17 and April 30, and two for May 14, 1912. From these curves it will be seen that at each inspiration the pointer on the spirometer rises and at each expiration falls. The experiments were so conducted that the communication between the subject and the spirometer was made at exactly the end of a normal expiration; consequently the first deviation from the straight line is that due to an inspiration. Similarly, at the end of the experiment the communication with the spirometer was cut off at the exact end of the normal expiration. From this record the respiration-rate can easily be counted.

Immediately below the record of the respiration is the line showing the time in minutes; the lowest line indicates the number of revolutions of the recording device—the so-called work-adder wheel—from which the total volume of ventilation is calculated. Since a record of the muscular activity is essential for all intelligent comparison of the results of respiration experiments, a method was followed similar to that used for the bed calorimeter, the bed upon which the subject lay being provided with a pneumograph, tambour, and pointer, by which a record of the degree of muscular repose was obtained. This record is shown in the line directly above the respiration curve. Frequent testing has shown that this form of bed[2] is extremely sensitive.

[1]See description and schematic outline of spirometer on p. 317 and figure 40.
[2]See arrangement of bed inside respiration calorimeter, figure 37, page 312.

In the curve for April 17, 1912, which was obtained near the beginning of the fast, it will be noted that the subject took a deep breath every 2 or 3 minutes, but in general the vertical height of the various lines indicates a fair regularity in the volume of air inspired. The record of the degree of muscular repose shows that during the whole period of 15 minutes the subject did not make a movement which could be recorded. As the recording device is so sensitive, it can be confidently asserted that the subject was in absolute muscular repose throughout

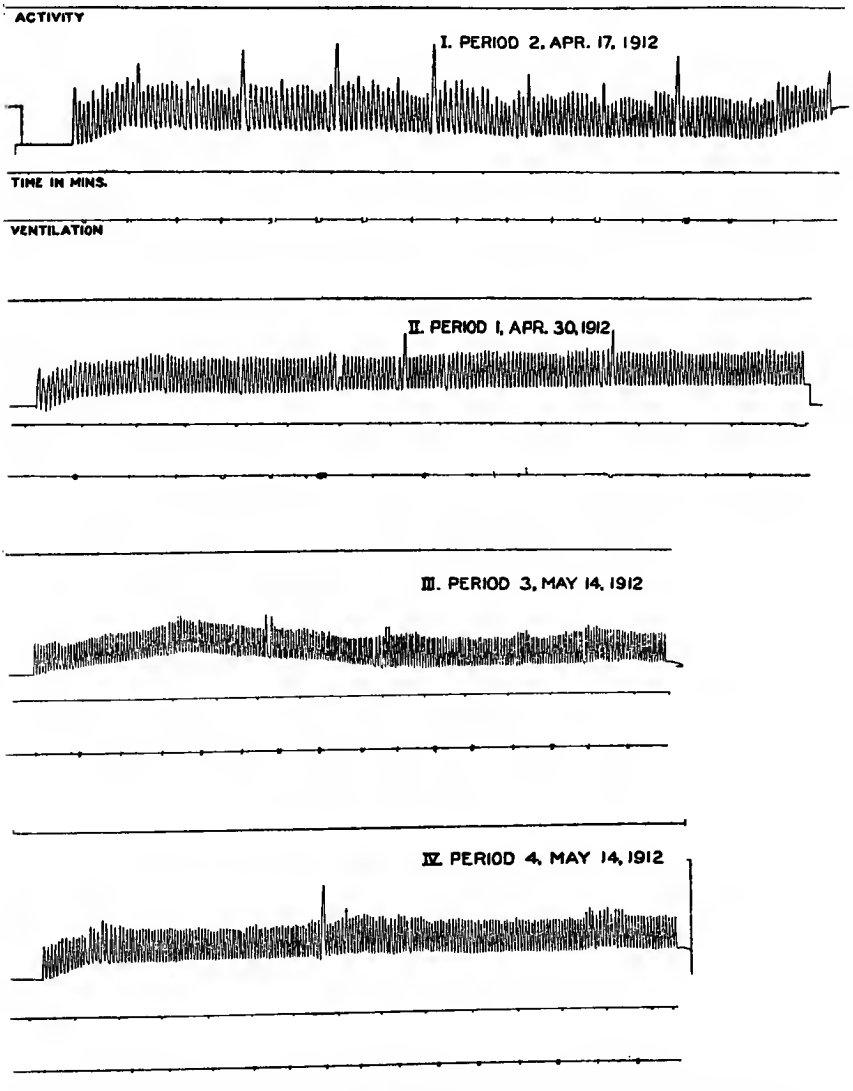
ACTIVITY
I. PERIOD 2. APR. 17, 1912
TIME IN MINS.
VENTILATION
II. PERIOD 1, APR. 30, 1912
III. PERIOD 3, MAY 14, 1912
IV. PERIOD 4, MAY 14, 1912

FIG. 22.—Specimen respiration curves for subject L. when lying on couch in experiments with the respiration apparatus.

the period so far as external muscular activity is concerned, although it is obvious that no idea of the muscular tonus can be obtained by this method.

The second curve, that for April 30, 1912, was obtained about the middle of the fasting period and is typical of many obtained about this time. In this respiratory record but two abnormally deep breaths are noted.

The third curve was obtained on May 14, 1912, at the end of the thirtieth day of the fast. In this record a greater frequency of respiration may be noted, with less amplitude, this being clearly shown even without measurement. The great sensitivity of the device for recording the degree of muscular repose is shown in the original kymograph curve by a wave-like line above the respiration record indicating the slight disturbance in the center of gravity of the body due to the respiratory movements. While this may be very plainly seen in the original curve, it is lost in the reproduction.

Immediately after the third curve was obtained, the apparatus was filled with pure oxygen, so that the subject breathed an atmosphere containing 95 per cent oxygen. One deep respiration is shown in the curve obtained (curve IV). The rate is apparently a little slower than in the preceding curve and the volume somewhat larger. The line above the respiration record again shows that the subject was absolutely quiet throughout the whole period, as was usual with this man.

METHOD OF CALCULATING THE TOTAL VENTILATION OF THE LUNGS.

The construction of the spirometer bell is such that each millimeter length corresponds to a volume in the bell of 23 c.c.; hence by measuring the vertical distance between the bottom and top levels of the record made on the kymograph drum by the pointer at the beginning and end of every inspiration or expiration, the apparent volume of air inhaled or exhaled may be computed. By measuring all the rising portions of the respiration curve and subsequently multiplying the result by the known factor, the total ventilation of the lungs during the experimental period can be obtained. To simplify this calculation, a recording device has been added to the spirometer which is somewhat in the nature of a work-adder wheel[1] and permits the accumulative measurement of the movements of the spirometer bell in one direction. Each revolution of this wheel corresponds to a rise in the spirometer bell of a certain number of millimeters, and from the record of the number of revolutions of this wheel the apparent volume of air passing through the lungs can be calculated.

In these experiments, the apparent volume obtained by this calculation was converted to standard conditions of temperature and pressure by multiplying it by the fraction $\frac{p}{760}$, in which p represents the baro-

[1]Benedict, Deutsch. Archiv f. klin. Med., 1912, **102**, p. 176.

metric reading corrected for scale correction and diminished by 5 mm. This correction of 5 mm. was found desirable as a result of experiments in which the humidity of the air inside the spirometer bell was found to be usually about 30 per cent. As a matter of fact, calculations showed that the difference due to using an assumed value for complete saturation or partial saturation is not more than 1 or 2 per cent. In addition to the correction for the pressure, the usual correction for temperature was made. The total volume as reported is therefore the total ventilation per minute, corrected for 0° C. and 760 mm. and likewise for an average value of 5 mm., corresponding to the probable humidity of the air inside the spirometer bell.

METHOD OF CALCULATING THE VOLUME PER INSPIRATION.

The method of calculating the volume per inspiration is not so simple as it at first appears. Instead of simply dividing the total ventilation per minute by the number of respirations, most writers have been accustomed to calculating the volume per inspiration from the volume of the air converted to the conditions which exist in the lungs, that is, the prevailing atmospheric pressure less the tension of water-vapor at 37° C. and corrected for the temperature of the lungs at 37° C. There has been considerable discussion, particularly in connection with the experiments of Galeotti,[1] and Loewy and Gerhartz,[2] as to whether the temperature conditions should be taken as 37° C., and whether the air is saturated at this temperature or not. This value is, however, most commonly used, and, indeed, we are not far in error in doing this, although, as was shown in an earlier publication,[3] the correct determination of the temperature of the air in the lungs and the degree of saturation will obviously affect these computations somewhat.

The method used for calculating our results is as follows: The total ventilation of the lungs, which has been reduced to standard conditions of 0° C. and 760 mm. pressure, is divided by the number of respirations. This value is then converted to the pressure existing in the lungs, which is the atmospheric pressure less the tension of aqueous vapor at 37° C., or 46.7 mm. It is subsequently converted to the temperature of the lungs by the usual calculation. A sample calculation will serve to show the method used: In the morning respiration experiment on April 11, the ventilation of the lungs was 5.32 liters per minute at 0° C. and 760 mm. The observed barometer was 758.7 mm. and the number of respirations per minute was 12.2. The volume per inspiration would therefore be

$$\frac{760\times(273+37)\times5.32}{(758.7-46.7)\times273\times12.2}=529 \text{ c.c.}$$

[1]Galeotti, Biochem. Zeitschr., 1912, 46, p. 173.
[2]Loewy and Gerhartz, Biochem. Zeitschr., 1912, 47, p. 343.
[3]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 436.

RESULTS OF OBSERVATIONS ON THE MECHANICS OF RESPIRATION.

The data secured by these methods regarding the respiration-rate, the ventilation of the lungs per minute, and the volume per inspiration give material for an interesting study of the effect of prolonged fasting upon the mechanics of respiration. These data are given in table 18, which shows two extensive series of values, one for the morning respiration experiments made directly after the subject came out of the

TABLE 18.—*Ventilation of lungs in experiments with L. at different times of the day, and with varying activity.* (*Respiration apparatus.*)

Date.	Day of fast.	Lying.					
		Usually 8h30m a.m. to 9h30m a.m.			Usually 7 p.m. to 7h 45m p.m.		
		Respiration-rate.	Lung ventilation per minute.[1]	Volume per inspiration.[2]	Respiration-rate.	Lung ventilation per minute.[1]	Volume per inspiration.[2]
1912.			*liters.*	*c.c.*		*liters.*	*c.c.*
Apr. 11	.....	12.2	5.32	529	....	....	....
12	.....	9.6	5.21	655	....	....	....
13	.....	9.6	5.19	650	....	....	....
14	.....	10.6	4.79	539	....	....	....
15	1st....	9.3	4.97	639	....	....	....
16	2d.....	10.9	5.18	576	....	....	....
17	3d.....	11.3	5.24	562	....	....	....
18	4th....	9.8	4.77	591	....	....	....
19	5th....	11.8	4.88	507	....	....	....
20	6th....	12.0	4.70	473	....	....	....
21	7th....	11.8	4.79	489	....	....	....
22	8th....	10.7	4.67	530	....	....	....
23	9th....	12.1	4.65	476	....	....	....
24	10th....	10.9	4.55	504	....	....	....
25	11th....	10.1	4.40	522	....	....	....
26	12th....	12.8	4.64	429	12.8	5.24	488
27	13th....	12.8	4.63	437	14.9	[3]5.35	[3]437
28	14th....	12.4	4.61	448	14.7	5.32	437
29	15th....	12.3	4.55	446	14.6	5.83	483
30	16th....	13.1	5.00	462	14.6	6.01	497
May 1	17th....	12.3	4.81	471	14.5	5.79	482
2	18th....	13.2	4.61	422	15.1	5.81	465
3	19th....	12.8	4.78	449	14.7	5.66	465
4	20th....	14.3	4.90	413	....	....	....
5	21st....	10.0	4.43	532	15.1	5.76	458
6	22d.....	13.5	4.91	436	14.9	5.69	460
7	23d.....	14.0	4.76	410	16.7	6.03	438
8	24th....	13.7	4.69	417	15.5	5.77	456
9	25th....	14.2	4.95	428	14.4	5.74	490
10	26th....	12.8	4.75	454	13.5	5.58	502
11	27th....	12.8	4.89	461	14.5	5.82	483
12	28th....	14.8	5.04	410	14.7	5.76	473
13	29th....	14.1	4.96	426	13.9	5.72	501
14	30th....	14.8	4.80	391	13.9	5.92	514
15	31st....	13.3	4.84	438	....	....	....
17	.....	9.9	3.93	485	....	....	....
18	.....	14.0	5.72	494	....	....	....

[1]The lung ventilation observed is here reduced to 0° C. and 760 mm. pressure.

[2]Calculated to the pressure existing in the lungs and to 37° C.

[3]During the period 3h 16m p.m. to 3h 51m p.m., with subject in lying position, the observations were: respiration-rate, 13.4; lung ventilation, 5.14 liters; volume per inspiration, 466 c.c.

TABLE 18.—*Ventilation of lungs in experiments with L. at different times of the day, and with varying activity. (Respiration apparatus.)*—Continued.

Date.	Day of fast.	Sitting.[1]			
		Period.	Respiration-rate.	Lung ventilation per minute.[2]	Volume per inspiration.[3]
1912.				*liters.*	*c.c.*
Apr. 16....	2d.....	$4^h\ 00^m$ p.m. to $4^h\ 35^m$ p.m.....	10.3	5.58	660
19....	5th....	4 10 p.m. 4 43 p.m.*...	17.9	7.54	517
23....	9th....	3 52 p.m. 4 28 p.m.....	16.7	5.48	402
24....	10th....	3 58 p.m. 4 57 p.m.....	14.6	5.83	484
26....	12th....	3 13 p.m. 4 11 p.m.....	15.8	5.37	404
27....	13th....	12 14 p.m. 12 48 p.m.....	12.8	5.55	525
29....	15th....	3 23 p.m. 3 56 p.m.*...	18.7	7.88	510
May 1....	17th....	9 31 a.m. 10 04 a.m.*...	14.6	6.57	542
4....	20th....	9 35 a.m. 10 10 a.m.*...	15.3	6.22	490
7....	23d.....	3 43 p.m. 4 14 p.m.*....	16.1	7.62	573
14....	30th....	6 32 p.m. 7 02 p.m.*...	17.8	8.05	546

[1]Periods indicated by an asterisk were obtained with the subject sitting, writing.
[2]The lung ventilation observed is here reduced to 0° C. and 760 mm. pressure.
[3]Calculated to the pressure existing in the lungs and to 37° C.

calorimeter and representing every day of the fast, and another series for the evening respiration experiments made each day during the latter part of the fast just before the subject entered the calorimeter.

RESPIRATION-RATE.

An examination of the respiration-rate for the morning period shows that there was a distinct tendency for it to increase as the fast continued, the lowest rate being observed on the first day of the fast, *i. e.*, 9.3 respirations per minute and the highest rate of 14.8 respirations, on the twenty-eighth and thirtieth days of the fast. The values obtained in the evening began on the twelfth day of the fast and indicate a reasonably constant respiration-rate, averaging not far from 15 respirations per minute. The evening rate in practically all cases was slightly higher than the morning rate.

Cathcart states that with his subject there was no change in the character of the respiration as the fast progressed, and his figures show a tendency for the morning respiration-rate to remain constant or to decrease slightly. Our observations, on the contrary, indicate a tendency to increase in the morning. Our findings also differ from those recorded by Luciani for Succi, as his curve indicates a tendency to fall towards the end of the fast. While on a number of days in Succi's fast the evening respiration-rate was higher than that obtained in the morning, in a large number of instances the reverse was true. In view of Succi's excitable temperament and the fact that his daily routine was not absolutely constant, it is more than likely that the discrepancies appearing between our results and Luciani's may be easily explained by the fact that in the experiment with Levanzin the routine was

rigidly adhered to each day, the subject lying very quietly for some time while the respiration-rates were being recorded.

The experiments of the Berlin investigators with Cetti and Breithaupt were not sufficiently long to make them comparable with this 31-day experiment and they were likewise complicated considerably by the fact that the subjects suffered from cold and colic.

From an examination of all of the kymograph records obtained with L., it is clear that while prolonged fasting tended to increase the average respiration-rate, there was great regularity of respiration throughout each 15-minute period. Occasionally a deep breath was taken, but there was nothing like the great irregularity noted by Zuntz and his co-workers on the two Berlin fasters, an irregularity which may again be explained by the complications of cold and colic.

VENTILATION OF THE LUNGS PER MINUTE.

The actual amount of air passing through the lungs was measured on the spirometer and its recording attachment. The ventilation of the lungs per minute, which is given for each experiment in table 18, followed a somewhat singular course. In the morning observations the ventilation per minute showed a persistent, though slight, tendency to decrease during the first 4 days with food; it then rose perceptibly in the first 3 days of the fast and subsequently decreased until the low value of 4.4 liters was reached on the eleventh day. This was closely approximated on the twenty-first day, when a value of 4.43 liters was obtained. The lowest value in the experimental period was found on the second day with food after the fast, when the ventilation was 3.93 liters. Few deductions can be drawn from these figures for the lung ventilation per minute, save that on certain fasting days the values were very low as compared with the four days preceding the fast, although, as has already been pointed out, the minimum value was obtained on the second day with food after the fast. Here again the values for the evening observations show an increase, the ventilation being invariably greater than during the morning experiments, rising at times as high as 6 liters. The average value was 1 liter higher than those obtained during the morning observations.

VOLUME PER INSPIRATION.

In discussing the values for the volume per inspiration given in table 18, it must again be stated that these were not obtained by dividing the total ventilation of the lungs by the number of respirations, but by using the volumes changed to the conditions in the lungs, as is commonly done by other writers of the present day. These figures show that there is a distinct tendency for the volume per inspiration to decrease as the fast progressed, although certain high values are found on the eighth, eleventh, and twenty-first days of fasting. On the other

hand, the lowest value recorded in the morning experiments—391 c.c.—was on the thirtieth day of fasting. In the evening series we note that while the values in general are somewhat higher than in the morning, this increase seems to become greater toward the end of the fast. Thus, on the thirtieth day of the fast it was 391 c.c. in the morning and 514 c.c. in the evening. While, therefore, there is a positive average difference, inasmuch as in the evening the volume per inspiration is greater than in the morning, the difference has a tendency to become very much greater in the last week of the fast.

INFLUENCE OF CHANGES IN BODY POSITION.

On a number of days the subject was studied when sitting in his chair, either resting or writing. The values obtained are given in table 18 for comparison with those found while the subject was lying on a couch. During the sitting experiments, when the subject was not writing, the respiration-rate was in practically all cases slightly higher than the values obtained in the morning respiration experiments while the subject was lying quietly. On the ninth day of the fast it increased from 12.1 to 16.7 respirations per minute. The ventilation of the lungs per minute also increased perceptibly in every instance, the increase being not far from 0.8 liter. On the other hand, the volume per inspiration varied considerably. In two instances there was a perceptible increase, on two other days it decreased, while on another day it remained essentially constant. This difference is not so apparent when the results are compared with the records for the evening respiration experiments. Unfortunately the sitting experiments were not sufficiently extended to draw any definite conclusions regarding the effect of the change in body position; furthermore, the whole study lacks suitable normal values for comparison.

INFLUENCE OF THE WORK OF WRITING.

On 6 of the fasting days the metabolism of the subject was studied while he sat in a chair and wrote actively. On 2 of these days he was studied in the forenoon and on 4 days in the afternoon. Since there is a tendency towards a diurnal variation in the mechanics of respiration between morning and evening, as shown by the increase in the respiration-rate and the ventilation of the lungs per minute, and the tendency for the volume per inspiration to increase, it is necessary to take this fact into consideration in discussing the results. In the two forenoon experiments there was in both instances an increase in the respiration-rate, a marked increase in the ventilation of the lungs per minute, and a great increase in the volume per inspiration. Inasmuch as the writing was accompanied by distinct, though perhaps slight, muscular effort, these findings are only what would be expected. In the afternoon experiments there was an increase in the respiration-rate much more

noticeable than in the experiments in the forenoon. The ventilation of the lungs per minute showed a large increase, the values averaging about 7.75 liters per minute. There was also usually a measurable increase in the volume per inspiration.

From these results it can be inferred that the slight muscular work of writing letters perceptibly affected the mechanics of ventilation in that the respiration-rate was somewhat increased and the ventilation of the lungs per minute noticeably so. So far as we know, no study has been made with normal individuals in which the ventilation of the lungs per minute and the volume per inspiration were so carefully observed as were those of our fasting subject, and hence we have no comparable values which will show to what extent the factors affecting the mechanics of respiration were influenced by prolonged fasting. It is reasonable to suppose, however, that muscular exercise of any kind would require a greater effort in the later stages of inanition. It is of particular interest that the lung ventilation per minute in the afternoon experiments was perceptibly greater than when essentially the same amount of work was carried out in the forenoon.

INFLUENCE OF BREATHING AN OXYGEN-RICH ATMOSPHERE.

On three days during the fast an experiment was made directly after the morning respiration experiment, in which the subject breathed an atmosphere containing from 95 to 75 per cent of oxygen. The influence of this increased amount of oxygen was distinctly noticeable with the ventilation of the lungs per minute and the volume per inspiration, although the respiration-rate changed but little. On the first day on which these experiments were made (May 12, 1912) the volume per inspiration with normal air was 410 c.c. and with the oxygen-rich mixture it was 487 c.c., an increase of 16 per cent. The values obtained in these experiments were as follows: Twenty-eighth day of fast, respiration-rate, 13.6, lung ventilation, 5.50, volume per inspiration, 487; twenty-ninth day, respiration-rate, 14.0; lung ventilation, 5.44, and volume per inspiration, 471; on the thirtieth day, respiration-rate, 14.2; lung ventilation, 5.34; volume per inspiration, 454. It is clear, therefore, that with this subject the breathing of oxygen-rich mixtures resulted in a considerable increase in the ventilation of the lungs per minute, and while the respiration-rate was not materially affected, there was a considerable increase in the volume per inspiration.

MAXIMUM EXPIRATION OF THE LUNGS.

As an index of a possible change in the volume of the lungs and particularly in the strength of the chest muscles, observations in regard to the maximum expiration of the lungs were made by Mr. Carpenter on 5 days during the fasting period. For these observations a long rubber tube was attached to a 10-liter Bohr meter. The subject stood up and,

while holding his nose, inhaled as deeply as he could, then placed the end of the rubber tube in his mouth and exhaled into the meter to the smallest possible volume of the lungs. The difference between the beginning and end readings on the meter gave the maximum apparent expiration. In computing the true volume of the expiration, these figures were corrected for the temperature of the air in the gas-meter, the barometer, and the temperature of the air in the lungs, the latter being assumed to be 37° C. The results are given in table 19.

TABLE 19.—*Maximum expiration of subject L. during fasting.*

Date.	Day of fast.	Time of observation.	Volume observed.	Barometric pressure.	Volume exhaled (computed).[1]
1912.			*liters.*	*mm.*	*liters.*
Apr. 15.....	2d.....	4h 35m p.m.	3.45	764.2	3.74
20.....	7th.....	3 00	3.60	762.0	3.91
May 7.....	24th.....	3 04	2.90	759.4	3.15
8.....	25th.....	3 30	3.00	752.6	3.24
14.....	31st.....	4 30	2.50	761.6	2.71
		4 36	2.45	761.6	2.66

[1]In computing these values it was assumed that the temperature of the air when exhaled was 37° C., and when passing through the meter it was between 23° and 23.8° C.

Although the volume on the seventh day of the fast (3.91 liters) was higher than that on the second day, a distinct tendency is shown for the volumes to decrease as the fast progressed. On the twenty-fourth and twenty-fifth days the volumes were essentially the same. Six days later—on the thirty-first day of the fast—the volume again materially decreased, as duplicate readings show values of 2.71 and 2.66 liters respectively.

One can hardly ascribe this marked loss in the volume of air expired, amounting to about 30 per cent, exclusively to change in the volume of the lungs as a result of the fasting or exclusively to the inability of the weakened muscles of the chest to compress the chest walls further. In all probability both factors contributed to this change in the volume of the expiration. The readiness with which the lungs respond to artificial atmospheric conditions leads one to believe that there may have been an absolute diminution in the available lung volume during the fasting period. On the other hand, there was unquestionably a falling off in the strength and general tone of the subject and he may not have been able to compress the lungs sufficiently to force out a large volume of air at the end of the fast.

ALVEOLAR AIR.

By Harold L. Higgins.

Observations were made of the carbon-dioxide percentage of the alveolar air nearly every day throughout this fasting experiment. This offered an index as to the acidity of the blood and also an opportunity to study the control and mechanics of respiration throughout the fast.

Alveolar air is the air which is in or comes from the alveoli of the lungs. As the active exchange of carbon dioxide and oxygen between the blood and the lungs takes place in the alveoli, it is readily seen that the tension or partial pressures of the different gases in the alveoli (carbon dioxide, oxygen, and also nitrogen, argon, etc.) will be very nearly the same in the alveoli as in the blood leaving the lungs. Inasmuch as the quantity of a gas dissolved in a liquid is proportional to the partial pressure, and not to the percentage of the gas, the composition of alveolar air is therefore probably better expressed in tensions or partial pressures than in percentages.

SIGNIFICANCE OF ALVEOLAR AIR.

Haldane and Priestley[1] have shown that carbon dioxide is the prevailing stimulus to respiration under normal conditions. Thus, if the carbon-dioxide tension in the respiratory center falls below a certain level, apnœa is the result; and if, on the other hand, it rises above this level, the respiration volume is greatly increased and hyperpnœa sets in. In other words, the respiratory center by respiratory impulses automatically keeps its carbon-dioxide tension constant. But the carbon-dioxide tension of the respiratory center is largely controlled by that of the arterial blood and the latter is, as mentioned previously, essentially that of the alveolar air. Haldane has therefore introduced the use of alveolar carbon-dioxide tension and shown that in any one individual it is practically constant under normal conditions, although the normal values of individuals may differ markedly from each other. It has been discovered that when there is an increased acidity of the blood, as in diabetic acidosis, or with reduced barometric pressure, as in high altitudes, the alveolar carbon-dioxide tension is lower than normal, and a smaller tension of carbon dioxide stimulates respiration. This has led to the presentation of the theory,[2] now quite satisfactorily established, that the H-ion concentration of the blood rather than the carbon-dioxide tension is the predominating factor in the control of respiration. Thus, when the H-ion concentration (or degree of acidity) of the blood coming to the respiratory center reaches a certain level, impulses are sent out from the center to increase

[1]Haldane and Priestley, Journ. Physiol., 1905, **32**, p. 225.
[2]Winterstein, Archiv f. die ges. Physiol., 1911, **138**, p. 167.

the respiration so that the net result is *always* the same H-ion concentration in the center.

The acidity of the blood may be divided into two parts, that due to carbon dioxide and that due to other acids. As the total acidity necessary to cause respiration must always be the same, it is readily seen that if the other acids in the blood increase in amount, less carbon dioxide is necessary to raise the acidity to the point of stimulation of the respiratory center. Thus, one may say that the quantity of carbon dioxide will vary conversely from that of the other acids of the arterial blood. Since alveolar carbon-dioxide tension represents so closely the carbon-dioxide tension of the arterial blood, it affords a very good index of the acidity of the blood. It was mainly for this reason that the alveolar carbon dioxide in the experiment with L. was so closely followed. In fact, it seems that this index of the degree of acidosis is much more satisfactory and important than the urinary tests for acidity (as β-oxybutyric acid, $\frac{NH_3-N}{N}$, total titratable acidity, etc.), because the former represents the acid actually in the blood, while the latter only represents that excreted from the body. The other factors which affect the alveolar carbon-dioxide tension, such as the absorption of food and varying postures, were avoided with L., and thus one is able to study the results almost purely from the point of view of blood acidity.

METHODS OF DETERMINING THE ALVEOLAR AIR.

HALDANE METHOD.

Haldane's method[1] for determining the alveolar carbon-dioxide tension is the oldest and probably theoretically the most sound of any of the methods now in use. By it one collects two samples of alveolar air from different phases of the respiratory cycle and averages their carbon-dioxide content. The two phases chosen are immediately at the end of an inspiration, which is approximately when the alveolar carbon-dioxide tension is lowest, and at the end of an expiration, when the alveolar carbon-dioxide tension is nearly at its highest point. The subject breathes normally for some time; then at the end of a normal inspiration he makes a rapid, deep expiration through a tube about 2 cm. in diameter and about 150 cm. long, sealing with his tongue the end he has just breathed into. A sample of the air in the tube near the mouth is then taken. This sample is considered to be alveolar air, as the air in the dead space of the respiratory passages and in that part of the tube from which the sample is taken has previously been pushed out by the air from the alveoli. Similarly a sample is taken of air forced through the tube from the lungs at the end of a normal expiration. Instead of sealing off the end of the tube with the tongue, use

[1]Haldane and Priestley, Journ. Physiol., 1905, **32**, p. 225.

has been made in our laboratory of a simple Siebeck[1] valve, which puts the subject under much less strain, as he does not have to hold his tongue to the tube while the sample is being taken into a gas-sampler. The average of the two analyses gives very closely the composition of the alveolar air.

The Haldane method requires considerable attention on the part of the subject and, as it was feared that possibly in the course of the long fast the subject would not be physically able to co-operate very satisfactorily, the method used in these tests was modified somewhat. In view of what we now know of the condition of the subject throughout the fast, we may feel assured that this method would have been very successful; but as several samples are often required to be sure of good agreement, and as it was probable that the subject's time would be much occupied, it was decided to modify the method somewhat to be sure of better agreement on fewer samples.

It has been observed that, in the Haldane method, holding the breath for several seconds before the expiration does not cause the percentag; of carbon dioxide in the alveolar air to increase with very great rapiditye this is naturally to be expected, for as the carbon-dioxide tensions of the alveolar air and the blood coming to the lungs approach the same figure, the increase in the former is slower. Furthermore, it appears that if a subject has previously been breathing somewhat abnormally for not over three or four respirations, the percentage of carbon dioxide in the alveolar air, after holding the breath for a few seconds, will be nearer that of the alveolar air when the breath is held similarly after normal respiration than is the percentage of carbon dioxide in the alveolar air of the same two cases when the breath is not held. Thus, it would seem that small deviations from the normal, such as appear in conscious respiration, would not be disturbing to agreeing results and that in a very small number of determinations (seldom more than two) figures can be obtained which are very good duplicates and which will bear a constant relation to the true alveolar carbon-dioxide tension when the subject is in the same position (sitting quietly).

The modified method used in these tests, which later is called the Haldane method, is as follows: The subject began by breathing normally into the room through a short (5 cm.) tube connected with the Siebeck valve. Then at the end of an inspiration, selected by the observer who was watching the respiration, the subject was told to hold his breath. At the end of 5 seconds, timed by the observer, during which the valve had been opened, the subject breathed out rapidly and deeply through the long tube as in the Haldane method. After the expiration the valve was again closed. Usually two samples were taken each day in which the subject held his breath 5 seconds and two in which he held his breath 8 seconds. The results obtained when the subject held his breath 8

[1]Dr. R. Siebeck, of Heidelberg, has devised an ingenious slide-valve for this purpose, which may be secured of Universitäts Mechaniker Runge in Heidelberg.

seconds average a trifle higher than when the breath was held for 5 seconds, but the agreement is so close that one could not satisfactorily select the individual determinations of each class if the results were put together and not labeled. The results were averaged, therefore, without distinction as to time. The determinations made in duplicate by this method agreed in general to 1 part in 20 and usually closer. To determine how close the results were to the figures which would have been obtained by the Haldane method, we experimented by both methods on ten different subjects sitting; the average result when the breath was held 5 seconds was 8.3 per cent higher and when held 8 seconds was 9.4 per cent higher than with the Haldane method. The averages of the 5 second samples and the 8 second samples are thus about 9 per cent higher than the Haldane figures. Excluding two of the ten cases (5 per cent and 19 per cent), none showed differences of more than 3 per cent (6 per cent to 12 per cent) from the average difference (9 per cent). Thus, for comparing the daily observations with each other, it appears that the values obtained with the 5-second and 8-second methods in the experiment with L. are practically as significant as if the Haldane method were used.

PLESCH METHOD.

Use was also made of the Plesch method[1] applied by Porges, Leimdörfer and Markovici[2] to clinical cases. By further modification of the method I have been able to get very constant duplicates with a minimum amount of attention by the subject. The apparatus used in this method consists of a woman's rubber bathing cap (pure gum), which is fastened to the bottom of an inverted shallow copper pan (about 20 cm. in diameter). On the other side of the pan is soldered a $\frac{3}{4}$-inch (2 cm.) three-way valve; by means of a rubber-tube connection the subject may breathe back and forth through this valve, either from the room or from the bag made of the bathing cap and the pan. A small brass stop-cock is attached to the pan, from which a sample of the gas in the bag may be obtained. In a determination, the bag was first emptied and 600 c.c. of the room air was admitted, the measurement being made by a meter. The subject then began breathing room air through the rubber tube and three-way valve, closing the nose with the thumb and forefinger of the hand holding the apparatus. At the end of a normal expiration the observer turned the valve and the subject breathed in all of the 600 c.c. of air in the bag. He then breathed back and forth at the rate of one complete respiration in 5 seconds, the time being followed by the observer, who instructed the subject when to breathe in and when to breathe out. At the end of 4 complete respirations, *i. e.*, 20 seconds, the three-way valve was turned and a sample taken in the gas-analysis apparatus for analysis.[3]

[1]Plesch, Zeitschr. f. exp. Path. u. Therapie, 1909, **6**, p. 380.

[2]Porges, Leimdörfer and Markovici, Zeitschr. f. klin. Med., 1911, **73**, p. 389.

[3]All the analyses of alveolar air were made on a portable Haldane apparatus. (Haldane, Methods of Air Analysis, London, 1912.)

This method is probably the most adaptable for use with the average patient, when the condition of acidosis is being compared from day to day, or when a gross picture of the degree of acidosis is desired. The method does not give the carbon-dioxide tension of the arterial blood, but seems rather to approach the carbon-dioxide tension of the venous blood, because, as the same air is rebreathed, it is obvious that the alveolar air, the arterial blood, and venous blood will all have eventually the same carbon-dioxide tension, namely, that of the venous blood, because it is the highest. For this reason, especially as it is the normal carbon-dioxide tension of the arterial blood, which is the important factor in the regulation of the respiration, this method theoretically is not so important as the Haldane method.[1] But with the subject in the same position and with the same amount of previous activity, we have found that the carbon-dioxide tension determined by this means bears a very constant relation to that of the Haldane method; this was assured from numerous comparisons of the different methods on many normal individuals, the results being about 20 per cent higher than the values obtained with the Haldane method. The same relation may also be observed with L., as the results in table 20 show that, excepting on the first few days, the difference between the 5- and 8-second Haldane method and the modified Plesch method is about 10 per cent.

METHOD OF CALCULATING ALVEOLAR AIR FROM RESPIRATION EXPERIMENTS.

The morning and evening respiration experiments, which were made with the universal respiration apparatus, included the determinations of the carbon-dioxide production, oxygen consumption, respiratory quotient, pulse- and respiration-rates, and inspiratory ventilation of the lungs. These experiments also give some data regarding the alveolar carbon-dioxide tension and the dead space of breathing, which are of interest in considering the other alveolar-air determinations. The dead space in respiration is the air that is inspired and again expired without entering the alveoli, in which active gaseous exchange takes place, and thus is unchanged. The following formula for calculating the percentage of carbon dioxide in the alveolar air is therefore readily understood:

$$\text{Alv. per cent } CO_2 = \frac{CO_2}{V - (DS \times R)}$$

CO_2 = CO_2 production in c.c.

V = Total volume of air *expired* in c.c.

DS = Dead space in c.c.

R = Number of respirations.

Naturally these factors must be measured for the same unit of time and under the same conditions of pressure, temperature, and aqueous tension. The unit of time chosen in the experiments with L. has been

[1] The same criticism applies to the 8-second and 5-second Haldane method as used in these experiments, although probably to a less degree.

1 minute, while the gas volumes considered in the application of the above formula have, for the sake of simplicity in calculation, been taken at 20° C., 760 mm., and dry.

Elaborating this general formula for use in connection with and calculation from the respiration experiment, we get the following:

$$\text{Alv.p.ct.}CO_2 = \frac{CO_2 \times 1.075}{V\left(\frac{P}{760}\right) - 0.015\ V\left(\frac{P}{760}\right) - 1.075\left(\frac{O_2 - CO_2}{2}\right) - (R \times DS)}$$

CO_2 = CO_2 production in c.c. per minute at 0° C. and 760 mm.; and $CO_2 \times 1.075$ = CO_2 production at 20° C., 760 mm.

O_2 = O_2 consumption in c.c. per minute, 0° C., 760 mm.

V = inspiratory ventilation of lungs per minute at barometer, temperature, and humidity prevailing in spirometer of respiration apparatus (*i. e.*, about 20°C. and 33 per cent or 66 per cent humidity).

$V\left(\frac{P}{760}\right) - 0.015\ V\left(\frac{P}{760}\right) - 1.075\left(\frac{O_2 - CO_2}{2}\right)$ = *expiratory* ventilation of lungs per minute at 760 mm., 20° C., dry.

DS = dead space in c.c. (20° C., dry, 760 mm.)

R = respiration-rate per minute.

P = barometric pressure.

1.075 = factor to convert gas volumes from 0° C. to 20° C.

In a respiration experiment the inspiratory ventilation is obtained at the pressure, temperature, and humidity of the air in the spirometer on the apparatus. The temperature is not taken in each experiment, but as it is probably very close to 20° C., this temperature is assumed in each calculation. The term $\frac{P}{760}$ obviously reduces the ventilation to 760 mm. The term $-0.015\ V\left(\frac{P}{760}\right)$ corrects for moisture in the spirometer; this moisture comes from two sources, namely, from the lungs of the subject and from the moistener used to prevent the air in the respiration apparatus from becoming too dry for comfortable respiration. Two kinds of moisteners were used during the fasting experiment. In the first part of the series (until April 22) a moistener constructed of the lower part of a Kipp gas-generator was employed. In this the air before coming to the nosepieces bubbles through water; the humidity with this form of moistener has been found to be 66 per cent saturated; 1.5 per cent of the recorded ventilation was therefore water-vapor and accordingly subtracted. The other moistener was a piece of moist cheese-cloth in the tube leading to the nosepiece. When this was used, the humidity in the spirometer was found to be only 33 per cent, so that in these experiments 0.75 per cent of the recorded volume was subtracted and not 1.5 per cent. The expiratory volume

is smaller than the inspiratory volume, because the amount of oxygen consumed is greater than the amount of carbon dioxide produced. Accordingly we subtract 1.075 (O_2-CO_2) from the inspiratory ventilation. But during inspirations in a respiration experiment one-half of the carbon dioxide produced is absorbed in the soda-lime bottles, so that the recorded inspiratory volume is correspondingly increased; on the other hand a volume of oxygen equal in volume to one-half the volume consumed is added to the respiration apparatus during an inspiration and thus makes the recorded inspiratory volume correspondingly too small. Thus, instead of 1.075 (O_2-CO_2), the factor for changing the inspiratory volume to the expiratory volume becomes

$$1.075\left(\frac{O_2-CO_2}{2}\right)$$

The only other factors in the equation are Alv. p. ct. CO_2 and DS. With either one known, the other may easily be determined. The formula for calculating the dead space is as follows:

$$DS=\frac{V\left(\frac{P}{760}\right)-0.015\,V\left(\frac{P}{760}\right)-1.075\left(\frac{O_2-CO_2}{2}\right)-\left(\frac{CO_2\times 1.075}{\text{Alv. p. ct. } CO_2}\right)}{R}$$

When the experiments on L. were made, we had not considered the possible use of this equation and so have not the complete data for calculating either of these factors, but we still have sufficient material to draw some interesting conclusions.

Assuming the personal dead space of breathing for the subject L., together with that of the nosepieces, etc., to be 120 c.c., the percentage of carbon dioxide in the alveolar air has been calculated for all of the morning and evening respiration experiments, and the results for each series have been averaged as shown in table 20. Also, making use of the alveolar-air figures found on the same day, the respiratory dead space in each experiment has similarly been calculated and averaged. As the alveolar air was not taken at the time of the respiration experiments and as the dead space might possibly have changed in size during the fast, fixed differentiation of the results is difficult. These results will be discussed later.

CONDITIONS OF TAKING ALVEOLAR-AIR SAMPLES

The samples were taken by the Haldane and Plesch methods with the subject sitting in an armchair. After the fast had begun, they were taken at about 1^h35^m p.m. to 2 p.m. Between the taking of the samples, each of which was analyzed before another was taken, the subject was sitting quietly and usually reading. On several days he had visitors while the experiment was in progress. On one of these days, April 22, while talking with a visitor, he became quite excited. On the other days there was no marked excitement while the samples were being taken. On April 22, it is interesting to note that the alveolar carbon-dioxide tension by the Haldane method was very low—in fact, much

lower than that calculated from the respiration experiments on the same day would seem to indicate it should normally have been. On 2 days, April 25 and 26, the alveolar air was not determined.

On the food days preliminary to the fast, the alveolar air was sampled with the subject sitting, immediately after the respiration experiment of the morning and the taking of the body-weight. On the morning of the first food day, April 11, the subject was unused to the apparatus and the tests were unduly hastened; the results obtained can not therefore be considered so reliable as on later days. The samples of alveolar air in the food days subsequent to the fast were taken at approximately $1^h\ 35^m$ to 2 p. m., as during the fast.

DISCUSSION OF RESULTS.

The results of the determinations made by the Plesch and Haldane methods are expressed in table 20, columns F and G, as tensions (millimeters of mercury). The tensions are calculated from the carbon dioxide obtained by the analyses. From the prevailing barometric pressure is subtracted the figure 46.7 mm., which is the aqueous tension of air saturated at 37° C. (the air in the alveoli being saturated with water-vapor at this temperature), and the resulting pressure is multiplied by the percentage of carbon dioxide found. Before discussing from a physiological point of view the results obtained by these methods it seems desirable to summarize first the results gathered from the respiration experiments.

SIZE OF DEAD SPACE IN FASTING.

A diminution in the size of the heart, liver, and other organs, as well as in the size of the muscular tissue, having been observed during the fast, the question was raised by Dr. Benedict as to whether or not the dead space in breathing also changed in size during the fast, and at his suggestion use was made of the formula given previously, and the data available, to calculate so far as possible a figure for the size of the dead space for each morning and evening experiment. To get a value for the alveolar carbon-dioxide percentage to use in these calculations, certain corrections have been made in the values obtained by the 5-second and 8-second methods given in column G of table 20. These corrections are necessary for two reasons: first, because the alveolar air was taken with the subject sitting, while in the respiration experiments the subject was lying on his back; second, because the results obtained by the Haldane method give a carbon-dioxide percentage about 9 per cent of the total less than that when the subject held his breath from 5 to 8 seconds. As shown in a recent paper,[1] the alveolar carbon dioxide lying is about 106 per cent of that sitting. Thus the alveolar percentage of carbon dioxide which should be used in calculating the dead space in the respiration experiments is 97 per cent of the figure from which column G is calculated, and is given in column A. In using

[1]Higgins, Am. Journ. Physiol., 1914, **34**, p. 114.

this value for each day, it was necessary to assume that the alveolar percentage of carbon dioxide had not changed between 8 a. m. or 8 p. m., when the respiration experiments were made, and 2 p. m. of the same day, when the alveolar percentage of carbon dioxide was taken. It would seem, however, that if there were a change in the

TABLE 20.—*Alveolar-air and dead-space determinations in experiment with L.*

Date.	Day of fast.	Alveolar air.										
		Alveolar CO_2 (Haldane), corrected to lying position.[1] A	Computed alveolar CO_2 (dead space = 120 c.c).									
			From morning respiration experiments.					From evening respiration experiments.				
			By periods. B			Average. C		By periods. D			Average. E	
1912.		*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*mm.* Hg.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*mm.* Hg.
Apr. 11	.....	....	4.76	....	5.11	4.94	35.2	....	....	....	....	....
12	.....	4.89	4.70	4.84	4.75	4.76	34.0	....	....	....	....	....
13	.....	4.94	4.80	4.89	4.99	4.89	35.1	....	....	....	....	....
14	.....	5.10	4.94	5.25	5.12	5.10	36.9	....	....	....	....	....
15	1st	4.43	4.76	4.91	4.60	4.76	34.3	....	....	....	....	....
16	2d	4.29	4.68	4.63	4.42	4.58	32.6	....	....	....	....	....
17	3d	4.37	4.29	4.30	4.30	4.30	30.6	....	....	....	....	....
18	4th	4.36	4.42	4.35	4.37	4.38	31.1	....	....	....	....	....
19	5th	4.33	4.50	4.65	[2]4.43	4.47	31.5	....	....	....	....	....
20	6th	4.30	4.39	4.51	4.43	4.44	31.7	....	....	....	....	....
21	7th	4.38	4.49	4.43	4.48	4.47	32.0	....	....	....	....	....
22	8th	3.94	4.36	4.31	4.36	4.34	30.9	....	....	....	....	....
23	9th	4.45	4.44	4.30	4.32	4.35	30.3	....	....	....	....	....
24	10th	4.29	4.23	4.31	4.21	4.25	30.4	....	....	....	....	....
25	11th	....	4.43	4.23	4.19	4.28	30.8	....	....	....	....	....
26	12th	....	4.42	4.42	4.27	4.37	31.9	3.65	3.64	3.63	3.64	26.4
27	13th	3.88	4.43	4.33	4.40	4.39	31.4	3.71	3.64	3.68	3.68	26.1
28	14th	3.95	4.17	4.10	4.15	4.14	29.6	3.92	3.58	3.45	3.65	26.1
29	15th	3.92	4.27	4.14	4.04	4.15	29.7	3.29	3.21	3.21	3.24	23.1
30	16th	3.74	3.79	3.75	3.76	3.77	26.9	3.04	3.05	3.07	3.05	21.8
May 1	17th	3.87	3.82	3.81	3.74	3.79	27.2	3.03	3.14	3.14	3.10	22.2
2	18th	3.90	4.10	3.87	3.83	3.93	28.1	3.08	3.07	3.15	3.10	22.2
3	19th	3.75	3.87	3.83	3.72	3.81	27.3	3.13	3.11	3.15	3.13	22.4
4	20th	3.64	3.82	3.75	3.67	3.75	26.9	....	....	....	....	....
5	21st	3.87	3.92	3.79	3.92	3.88	27.9	3.03	3.05	3.04	3.04	21.9
6	22d	3.77	3.74	3.63	3.54	3.64	26.2	3.07	2.96	3.21	3.08	22.1
7	23d	3.78	3.71	3.95	3.75	3.80	27.2	3.12	2.90	....	3.01	21.4
8	24th	3.68	3.97	3.80	3.86	3.88	27.5	3.12	2.98	3.14	3.08	21.7
9	25th	3.77	3.79	3.74	3.60	3.71	26.1	2.95	2.97	3.00	2.97	20.9
10	26th	3.84	3.74	3.76	3.92	3.81	26.9	3.11	3.14	3.15	3.13	22.2
11	27th	3.72	3.64	3.81	....	3.73	26.7	2.92	3.01	3.03	2.99	21.4
12	28th	3.78	3.78	3.71	3.48	3.66	26.2	2.92	2.96	3.00	2.96	21.1
13	29th	3.84	3.73	3.62	3.65	3.67	26.1	2.91	2.95	2.96	2.94	20.8
14	30th	3.77	3.83	3.87	3.69	3.80	27.2	2.89	2.88	....	2.89	20.7
15	31st	[3]4.33	3.60	3.64	3.47	3.57	25.6	....	....	....	....	....
16	.....	[3]4.36	....	....	....	....	....	....	....	....	....	....
17	.....	[3]4.83	4.73	4.68	[2]4.77	4.70	33.2	....	....	....	....	....
18	.....	....	4.06	4.15	[2]4.06	4.11	29.3	....	....	....	....	....

[1]Obtained by taking 97 per cent of the percentages alveolar CO_2 from which the figures in column G were calculated.

[2]Calculated percentages for the fourth period on April 19, 4.31; May 17, 4.60; May 18, 4.18.

[3]The subject ended his fast with the taking of fruit juices and honey on the morning of May 15, afte the conclusion of the respiration experiments.

alveolar air during that time, it would be proportional on each day; on certain days subsequently specified there is good reason to believe that the change was not proportional. The results of these calculations are given in column H for the morning experiments and J for the evening experiments, with the averages in columns I and K, respectively.

TABLE 20.—*Alveolar-air and dead-space determinations in experiment with L.*—Continued.

Alveolar air.		Volume of dead space (using alveolar CO_2 in column A).								Day of fast.	Date.
CO_2 tension for sitting.		Computed from morning respiration experiments.				Computed from evening respiration experiments.					
Modification of Plesch method. F	Haldane method (breath held 5″ to 8″). G	By periods. H			Average. I	By periods. J			Average. K		
mm. Hg.	*mm.* Hg.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.		1912.
31.9	31.7		...	...	...	...	...	...	...	.....	Apr. 11
35.4	36.0	141	124	132	132	...	...	...	...	.....	12
35.1	36.5	135	124	116	125	...	...	...	...	.....	13
35.7	37.5	130	110	118	119	...	...	...	...	.....	14
33.7	32.8	85	80	98	88	...	...	...	...	1st	15
33.7	31.3	90	84	108	94	...	...	...	...	2d	16
33.1	32.1	127	126	126	126	...	...	...	...	3d	17
35.4	31.9	115	121	120	119	...	...	...	...	4th	18
34.1	31.4	109	96	[1]111	109	...	...	...	...	5th	19
34.7	31.6	114	105	111	110	...	...	...	...	6th	20
35.3	32.3	112	117	113	114	...	...	...	...	7th	21
34.4	28.7	86	86	81	84	...	...	...	...	8th	22
34.3	32.1	120	130	128	126	...	...	...	...	9th	23
34.0	31.5	126	118	126	123	...	...	...	...	10th	24
....	....	...	...	...	...	...	...	...	...	11th	25
....	....	...	...	...	...	...	...	...	...	12th	26
32.8	28.4	84	88	82	85	132	136	133	134	13th	27
32.4	29.1	103	109	107	106	122	145	156	141	14th	28
31.6	28.9	96	105	111	104	169	175	179	174	15th	29
30.8	27.5	116	119	118	118	178	184	177	180	16th	30
30.0	28.5	124	125	130	126	190	176	179	182	17th	May 1
31.4	28.7	107	122	125	118	183	179	179	180	18th	2
29.3	27.6	111	114	122	116	168	172	166	169	19th	3
30.1	26.9	107	112	118	112	...	...	...	...	20th	4
30.0	28.7	115	127	116	119	179	187	182	183	21st	5
30.5	27.9	122	130	138	130	176	181	164	174	22d	6
29.5	27.8	125	110	122	119	165	185	...	175	23d	7
29.1	26.8	100	112	108	107	164	175	160	166	24th	8
29.7	27.3	119	122	131	124	189	185	182	185	25th	9
29.2	28.1	127	126	114	122	185	179	177	180	26th	10
29.4	27.5	126	113	...	120	191	178	175	181	27th	11
29.9	27.9	120	125	140	128	190	184	183	186	28th	12
29.1	28.1	127	135	133	132	197	196	193	195	29th	13
29.7	27.8	116	114	125	118	208	192	...	200	30th	14
[2]33.2	[2]31.8	...	...	...	...	...	...	...	...	31st	15
[2]35.0	[2]32.0	...	...	...	...	...	...	...	...	.....	16
[2]38.0	[2]35.1	126	129	[1]124	128	...	...	...	...	.....	17
....	....	...	...	...	...	...	...	...	...	.....	18

[1]Calculated volume of dead space for the fourth period on April 19, 121 c.c.; May 18, 133 c.c.

[2]The subject ended his fast with the taking of fruit juices and honey on the morning of May 15, after the conclusion of the respiration experiments.

Considering each series by itself, the conclusion may be drawn from both the morning and the evening experiments that there is no constant change in the size of the dead space of breathing as a result of the fast. Although there is more or less fluctuation from day to day, yet the general average of dead-space volumes found at the beginning of the fast is much the same as that toward the end of the fast. A number of very low values may doubtless be explained quite well as follows: On April 15 and 16 there is a markedly lower value for the dead space; this is probably due to an especially large drop in the alveolar air during the day, as one might perhaps expect, these two days being the first two of the fast. As previously mentioned, the subject was much excited on April 22, when the Haldane samples were taken, and as a result the value obtained for the alveolar air was probably low; thus the calculation makes the dead-space figures also too low. On April 27 and 28 there is also an indication of a lower dead space; this is likewise probably due to a change in the alveolar air, as it will be noted that table 20 shows a marked fall in the alveolar carbon-dioxide tension about this date.

DIFFERENCE IN MECHANICS OF RESPIRATION IN MORNING AND EVENING.

On comparing the values for the dead space calculated from the evening experiments with those for the morning experiments, one finds a constantly higher dead space, which is, on the average, 55 c.c. This, of course, is based on the assumption that the alveolar percentage of carbon dioxide is the same in the morning as it is at night. Since some physiologists believe that the dead space is always essentially the same, it seems desirable to consider how large a difference in the alveolar percentage of carbon dioxide must have existed between the morning and evening experiments to indicate so marked a change in the ventilation. Assuming for the size of the dead space the figure 120 c.c., which represents approximately the mean value previously calculated for the dead space in the morning experiments, the alveolar air has been computed for each respiration experiment, as shown in columns B and D and the averages in columns C and E. The alveolar percentage of carbon dioxide (carbon-dioxide tension) in the morning experiments shows, in general, the same changes that the alveolar carbon-dioxide tensions by the other methods have indicated. In fact, the alveolar carbon-dioxide tensions obtained in this manner very satisfactorily supply the values for April 25 and 26, when the alveolar air was not taken by the other methods. The close agreement of the values for the alveolar percentage of carbon dioxide in the several duplicate experiments gives evidence of the even and normal respiration of the subject and the great care in making the respiration experiments.

If the alveolar carbon-dioxide tensions of the morning and evening experiments of the same day are compared, an average difference is

found of 5.4 mm. (0.7 per cent). It is difficult to interpret accurately this change in the mechanics of ventilation, but it is clear that it exists, for with a given output of carbon dioxide, the respiration volume is much larger in the evening than in the morning. Two causes for this are possible—one, a lower percentage of carbon dioxide in the alveolar air, the other an increased volume in the dead space of respiration. Both causes may be in part responsible for the difference. If the alveolar air had been taken in the evening and in the morning at the same time as the respiration experiments, the exact cause could have been located; but unfortunately the data are not available. However, this change seems of sufficient importance to summarize possibilities.

A lower alveolar carbon-dioxide tension in the evening will mean, perhaps, a higher acidity of the blood toward evening, or possibly a respiratory center *more* sensitive to a given stimulus. FitzGerald and Haldane[1] have noted that the alveolar carbon-dioxide tension falls as a subject becomes mentally tired. Ordinarily this fall would not be noticed during the day, as the food eaten tends to raise the alveolar carbon-dioxide tension and thus renders the figures uncertain; but in a one-day fasting experiment with myself as subject, I failed to find any fall in the alveolar carbon-dioxide tension up to $4^h\ 30^m$ p. m., when the experiment stopped.[2] Changes in the dead space have been reported by Douglas and Haldane,[3] who state that with muscular work a larger dead space is found, which would lead to the general conclusion that the dead space increases with increasing metabolism. Krogh,[4] however, using different experimental methods, maintains that the dead space is practically always the same. As the metabolism in the evening experiments is only about 10 per cent higher than in the morning, it seems unlikely that this higher metabolism would of itself cause the change in the dead space, especially as the subject was at complete rest and in the same position in both cases. In experiments carried out by Dr. J. H. Means, of the Massachusetts General Hospital, and myself, we have found changes in the dead space as the result of drugs which correspond very closely to such changes as may have occurred here. It seems quite possible that the bronchi became dilated in the latter part of the day, having lost some of their tone with increasing fatigue. Any changes in the dead space which may have occurred in the experiments with L. are of such size that they can readily be explained by dilation of the bronchi.[5]

In this connection it may be well to state that the dead space given in table 20 includes the volume of the inspired air, measured at 760 mm. and 20° C., dry, which does not reach the alveoli, where active exchange

[1]FitzGerald and Haldane, Journ. Physiol., 1905, **32**, p. 486.
[2]Higgins, Am. Journ. Physiol., 1914, **34**, p. 116.
[3]Douglas and Haldane, Journ. Physiol., 1912, **45**, p. 235.
[4]Krogh, Journ. Physiol., 1913, **47**, p. 30.
[5]Siebeck, Skand. Archiv f. Physiol., 1911, **25**, p. 81.

of gas takes place. As L. was breathing through the three-way valve and nosepiece connected to the apparatus, the figures given are 30 c.c. higher than his actual personal dead space, since the subject with each respiration drew from the air system of the apparatus 30 c.c. which did not reach either the respiratory passages or the lungs.

SIGNIFICANCE OF CHANGE IN THE ALVEOLAR AIR DURING THE FAST.

Finally, it is advisable to compare the data of the alveolar carbon-dioxide tensions as the fast progressed. Columns C, F, and G, in table 20, serve this purpose the best. As one would naturally expect, there is a drop in the alveolar carbon-dioxide tension with the increased acidosis of the fast. The subject ate the last meal before fasting on the evening of April 13; on the afternoon of April 15 the fall in the alveolar carbon-dioxide tension is first noted. This fall is about 4 to 5 mm. (2 mm. Plesch method); after this the alveolar air continues at about the same level until April 27 or 28, when a second quite sharp drop, also of about 4 to 5 mm., is apparent. The new level is maintained with only slight fluctuations until the end of the fast. With the taking of food again, there is a rise in the alveolar carbon-dioxide tension, as would be expected with the resulting diminution of acidosis. On the morning of May 18 a slight fall in the alveolar carbon-dioxide tension is again noted in connection with the respiration experiments before breakfast. Possibly a part of the rise on May 15 and subsequent days with the Plesch and Haldane methods may have been due not only to the diminution of acidosis, but to an effect similar to that since noticed in this laboratory with the ingestion of food.[1]

In connection with the second sharp fall in the alveolar carbon-dioxide tension, it is of interest to note several parallel experimental findings. The chlorine excretion in the urine on April 27 and 28 dropped from a previously high level to a lower figure, at which it continued for the remainder of the fast. A rise in the total volume of the urine occurred also at about this time. The daily nitrogen excretion in the urine for the first 10 or 12 days of the fast was slightly over 10 grams; there was then a fall to about 8 grams, which was maintained throughout the rest of the fast. It may be noted that this drop in the nitrogen excretion is simultaneous with the drop in the alveolar carbon-dioxide tension.

Since alveolar air is intimately associated with the acidosis of the subject, one naturally looks for simultaneous changes in the factors of the urine which are taken as indicators of acidosis. Thus the β-oxybutyric acid seems to show a rise to a high level about the twelfth day of the fast; such a change is difficult to judge, however, as the β-oxybutyric-acid variations from day to day are quite large. The other index, the ratio of ammonia nitrogen to total nitrogen, also shows a

[1]Higgins, Am. Journ., Physiol., 1914, 34, p. 117.

simultaneous rise by reason of the increase of the ammonia and the decrease of the total nitrogen.

From these data one may safely conclude that there is a marked increase in the acidity of the blood in the fast, beginning on the second day; the acidity then did not change markedly until about the fourteenth day of the fast, when another decided increase in blood acidity occurred. The recovery to normal acidity in the blood begins to be evident in the first few days after the fast.

CONCLUSIONS.

The results for the alveolar air and dead space may be summarized as follows:

(1) On the second day of the fast, the carbon-dioxide tension in the alveolar air showed a drop from the normal value. It remained at this new level until about the fourteenth day of the fast, when there was a second rather sharp fall, after which no further marked change occurred. Each of these falls is about 4 mm. Thus the blood acidity may be said to have markedly increased on the second day of the fast and to have remained at this higher level until the fourteenth day, when a second increase occurred; there was no further change until the end of the fast.

(2) There is no sign of an accumulative change in the size of the dead space from day to day as the fast progressed.

(3) A change in the mechanics of respiration on the respiration apparatus between morning and evening experiments during the fast shows that there was either a marked change in the alveolar air or else a change in the size of the dead space during the course of each day. If the former, the alveolar air fell about 6 mm. between morning and evening, returning during the course of the night to essentially the morning figure. If the dead space changed, it increased in size about 55 c.c. and again became normal by the next morning.

SUBJECTIVE IMPRESSIONS AND MENTAL ATTITUDE TOWARD THE FAST.

By Harry W. Goodall, M. D.

The freedom of speech characterizing this subject, his preconceived ideas on fasting and on the humanitarian service of his fast led to exceptionally full comments on the whole project and specifically his subjective impressions. His habit of thought and introspection probably make them of average value, though admittedly they are recorded not as scientific observations, but as general indices to his mental makeup, his personal experiences and his beliefs, as outlined freely to the writer on each visit.

SUBJECTIVE IMPRESSIONS.

April 14, 1912 (18 hours after beginning the fast):

The subject states that he is very happy in the thought that the fast has actually begun. The value of the experiment to the world can not be estimated, and after a few days the mind will be clear and active. In explaining the influence of fasting upon the mind, he stated that on his long journey from Malta he had been obliged to eat food that was poisonous, more especially animal foods, and that his body was saturated with this poisonous waste, making the mind dull and causing a kind of physical fatigue. "When these waste matters are eliminated the mind will be clear, and I will feel buoyant and hopeful." In referring to the nocturnal emission which occurred during the night of April 12–13, he stated that one of the most important things noted in connection with his fasts was the behavior of the sexual organs. During fasting there is a reversion to the animal type, a periodicity of sexual desire at monthly intervals. In speaking of his subjective sensations since beginning the fast, he states that he feels perfectly well, has had no sensations of hunger, and no thought of food. He has been a mouth breather for years. Is troubled with naso-pharyngitis and tinitus aurium. Both these conditions always improve with fasting.

April 16, 1912 (third day of fast):

Feels perfectly well. Has had no sensation of hunger, and no abdominal sensations, aside from slight rumbling of gas in the intestines. Has passed very little odorless gas by rectum; there has been no belching of gas, no sense of fatigue. Mind is not yet clear enough for active mental work.

April 18, 1912 (fifth day of fast):

Feels perfectly well. No sensation of hunger. No longing for food, but occasionally thinks of the agreeable taste of ice cream. No sense of muscular weakness or fatigue. Has passed a little odorless gas by rectum. Naso-pharyngitis and tinitus better.

April 20, 1912 (seventh day of fast):

Mentally depressed yesterday and to-day. He attributes this to the rain and cloudy weather, as he always feels depressed when the sun does not shine. Feels as well physically as usual. Expressed his satisfaction at the manner in which the fast was being conducted.

April 22, 1912 (ninth day of fast):

Feels well and hopeful again. Only complaint is the sensation of a dry coating of the pharynx and a bad taste in the mouth. No sensation of hunger. Not conscious of his stomach. Has passed a little odorless gas.

April 24, 1912 (eleventh day of fast):

Is conscious of slight muscular weakness but otherwise feels well. No loss of ambition. No sensation of hunger and reading about food does not stimulate a desire to eat. There is no dryness in the pharynx today. Still passes a little odorless gas by rectum. Says he is thirsty for the first time.

April 26, 1912 (thirteenth day of fast):

Still conscious of slight muscular weakness. Has no special inclination for mental work. Still has the sensation of thirst. No sensation of hunger. Still passes a little odorless gas by rectum. Expressed satisfaction at the progress of the fast.

April 28, 1912 (fifteenth day of fast):

No depression to-day. Mind is clear now. Desires to study. No sensation of hunger. Mouth, which has tasted bad since the ninth day of the fast, is now improving. Passes very little odorless gas by rectum. Had nocturnal emission at 6 a. m.

April 30, 1912 (seventeenth day of fast):

Mind is clear. Feels well. Ambitious to study. Conscious of slight muscular weakness. No sense of hunger.

May 2, 1912 (nineteenth day of fast):

Feels somewhat weaker physically, but mind is clearer and can do better mental work. Thinks the poisons of the food ingested previous to the fast are about eliminated now. Complains of a "bilious taste" in the mouth to-day. No sensation of hunger.

May 4, 1912 (twenty-first day of fast):

Feels practically the same as he did May 2, except that he is a little depressed by the cloudy weather and by remaining indoors.

May 6, 1912 (twenty-third day of fast):

Feels a little brighter to-day. Conscious of physical weakness. Mouth does not taste so bad. No desire for food.

May 8, 1912 (twenty-fifth day of fast):

Feels very well. No desire for food. Still passes a little odorless gas by rectum.

May 10, 1912 (twenty-seventh day of fast):

No change from last note. Still has a bad taste in his mouth.

May 12, 1912 (twenty-ninth day of fast):

Sense of physical weakness, but to-day is very ambitious for his studies and writing. Feels more hopeful and clearer mentally. Pleased with the progress of the experiment. No desire for food.

May 14, 1912 (thirty-first day of fast):

Depressed mentally because he has to break his fast tomorrow. States that the fast should not be broken until the tongue has become clean and a desire for food has returned. This in his opinion would take several more days. To break the fast at this time is injurious. Aside from this he is pleased with the manner in which the fast has been conducted, and congratulates himself that he has been able to go through with it successfully. Says the time has passed very quickly. To-day he feels well. Has no particular weakness, but has been conscious of some muscular fatigue since the eleventh day of

May 14, 1912—Continued.

the fast. This, however, is no more marked than it is many days when he is taking regular meals. The most pronounced physical change is a sensation that his body is very light. This has gradually developed as his weight has decreased, and necessitates his measuring his steps when he walks. Says that at no time has he felt like reclining on account of body fatigue. His neurasthenia is greatly improved, and during the entire fast has only shown itself as slight despondency and some irritability on the rainy days. His mind has been much clearer throughout the fast than it is when food is taken. To-day his mind is clear. He has better imagination. He is full of hope and courage. Is ambitious to do mental work. Has had no sensation of hunger, no sensations of faintness. He had no desire for food, aside from the pleasant thought of ice cream on the third and fourth days of the fast, and has been glad that he did not have to eat. Has had no abdominal pain or discomfort. His nasopharyngitis is much improved, and his tinitus has practically disappeared.

May 15, 1912 (two hours after breaking fast):

Extremely depressed and despondent because he had been obliged to break his fast before his body was prepared for it. Felt very weak physically. The foods that he selected in breaking his fast were concentrated orange and lemon juice, grape juice, and honey. Experience had taught him that these were the only natural, rational foods to be taken at this time. Meat broths and other animal foods were poisonous. In his opinion these natural foods should be followed first by cooked fruits, then vegetables, and later a return to the ordinary diet. Stated that he had no appetite, and that nothing tasted good, although the lemon juice was not unpleasant.

10 a. m. Food was first ingested. This immediately caused a sensation of warmth in the stomach, and he was conscious of a pulsation in the epigastrium. There was no desire to belch gas, no nausea or other symptoms until—

11h 45m a. m. when he began to have distress in the abdomen, starting in the epigastrium and radiating towards the right hypochondrium. The pain was dull, intermittent in character, but not colicky. He describes it as a sensation of distension of the stomach accompanied by rumbling and belching of gas. Furthermore, he believed he could feel the progress of the distension of the alimentary tract as the ingested food moved along the intestines, and he felt by—

12h 10m p. m. that the food had proceeded as far as the right iliac fossa. Then at—

1 p. m. the rumbling and belching of gas was much more marked and the pain was somewhat more severe. Marked lassitude and depression. Soon after pain became easier, until—

4h 15m p. m., when the character of the pains changed from the "pains of distension" to intermittent attacks of cramp-like or colicky pain, which became very severe. These were experienced about the umbilicus and in the lower abdomen. Between the attacks he was very drowsy. The colic gradually increased in severity until—

5 p. m., when he defecated for the first time. This was accomplished without difficulty or pain. There was some gas, and the movement had a very bad odor. After this he was free from pain until—

5h 45m p. m., when the cramps began again, increasing in severity, the location being the same. This time the pain made him extremely

May 15, 1912—Continued.

weak. There was profuse perspiration and intense thirst. This continued until—

7h 15m p. m., when he had a second movement of the bowels, liquid in character. After this he was nauseated, and the pain continued severe until—

9h 45m p. m., when he vomited and then began to feel better, and at—

11 p. m. the pain stopped.

May 16, 1912 (second day after breaking fast):

About 2 a. m. began to have severe abdominal cramps again, continuing until—

2h 30m a. m., when he had a third movement of the bowels, liquid in character. After this he was comfortable, but passed gas at frequent intervals. The odor of the gas was very disagreeable, but the passage was not accompanied by pain. Was comfortable until—

8 p. m., when he stated that he was in no physical distress, but that he was very despondent. He appeared hysterical, crying a good deal. He was offended because he had been obliged to break the fast, and complained that this, together with a few disagreeable experiences with some of the men in charge of the experiment, and the lack of fresh air and exercise throughout the fast, was responsible for his physical and mental weakness. He attributed the abdominal pain to the presence of gas. Inasmuch as he had not defecated during the fast, "a hard plug of intestinal secretion had accumulated in the rectum, and when he took food the advancing bolus compressed the gas present in the intestines, causing pain."

May 17, 1912 (third day after breaking fast):

Feels very weak, but no abdominal pain for past 24 hours. Passed a fairly comfortable night, but did not sleep as well as usual. Is still depressed and emotional, but to a much less degree since the pain stopped. Is taking the same kinds of food, but well diluted with water, as was suggested to him. Feels much better physically, but has no ambition for mental work. Late yesterday afternoon he was very thirsty for about an hour, drinking 5 glasses of water. Up to the present time he has eaten the juice of two lemons diluted with equal parts of water and sweetened with a teaspoonful of honey, also 1,500 c.c. of orange juice diluted one-third with water, to which enough honey was added to make it sweet. Says his general condition is not nearly so good as it was on the last day of the fast. His appetite is just beginning to return, but he is not hungry yet.

May 18, 1912 (fourth day after breaking fast):

Extreme mental depression. Marked excitability, hysterical in character. Weeps when spoken to, and his voice is scarcely audible. Complains of general weakness, almost prostration. Sensation of trembling all over the body. Did not sleep one moment during the entire night. Beginning at 5 a. m. he had three loose movements of the bowels preceded by severe colicky pains. He attributes this diarrhea to worry. Can not bear the thought of food to-day. Explains his mental state as being due to his general dissatisfaction at his treatment at the laboratory. Later in the day, at his own request, he was sent to a private room in the Massachusetts General Hospital. Upon admission his condition was fully described by the writer to the resident physician and the visiting physician.

May 19, 1912 (fifth day after breaking fast):

Was seen at the Massachusetts General Hospital at 9 a. m. At the time he was sitting on one of the verandas reading. While he still appeared somewhat emotional, he said he was no longer depressed, but was in a most cheerful state of mind. He expressed his regret for the trouble he had caused at the laboratory, and said he was so nervous and irritable that he did not realize just what he was doing. He sent his apologies to Professor Benedict, and wished me to say that he would be glad to go back to the laboratory and go into the calorimeter again, if it would add anything to the value of the experiment. When asked about his comfort at the hospital, he said he was very much pleased with the care and attention he was getting. His appetite had returned, and he had relished his breakfast of "Boston baked beans," which he ate for the first time.

May 20, 1912 (sixth day after breaking fast):

The hospital reported that he had voluntarily left the institution. His reason for leaving could not be learned, but in so far as could be determined he had no grievance.

October 19, 1912 (five months after breaking fast):

On account of the sensational stories which were circulated, an effort was made to obtain as much information as possible regarding the personal experiences of the subject after leaving the hospital. He was first questioned as to the reason for leaving the hospital so abruptly. First of all he stated that he was not sincere in his remark regarding the hospital, as noted under the date of May 19. His reasons for misrepresenting the true condition was a fear that he would not get good treatment if he made any complaints. He was quite dissatisfied at the hospital. In the first place, his pride was injured in that he was not given the attention which was due an individual of his standing. One grievance was the fact that he was recorded on the chart as "A laborer from the island of Java." Another was the fact that, although he was in a room by himself, there were a good many rooms in the ward and he was obliged to use the common toilet and bathroom. Still another was the fact that the physicians at the hospital had no experience in fasting and did not order the proper food for him. The day following his admission he was given milk and eggs, and he believed that these animal foods would poison his blood and spoil all the benefits of the fast. The ingestion of the food was followed by cramps and diarrhea, and he thought he was delirious. The following morning (May 20) he looked at his chart, and finding his temperature recorded at 99 degrees and his pulse-rate 90, he knew he was being poisoned and hastily left the institution.

When he reached the street he did not know where to go, inasmuch as he was entirely unfamiliar with Boston. Being a newspaper editor himself, he thought he would find trustworthy advice as to where to go by consulting an editor of one of the Boston papers. He then took a cab to the office of one of the newspapers, the editor of which engaged a room for him at one of the large hotels. In his room at the hotel he was visited by some of the staff of the paper and talked the situation over with them. He was surprised to find an account of his fast, with photographs of himself, in the paper the following morning, as he thought he was speaking in confidence and he was not aware that photographs were being taken.

October 19, 1912—Continued.

After spending one night at the hotel, he was disinterestedly (!) advised by the editor to go to some secluded place to avoid annoyance from reporters from other papers. In accordance with this advice the editor arranged for his care at Bridgewater, Mass., agreeing to take care of his expenses for three weeks, and later start him on a lecture tour in return for information concerning the experiment and his treatment at the laboratory. He went to Bridgewater, accompanied by a reporter who visited him each day, and was delighted with the place. On the way down he talked freely with the reporter. The next morning he was given a copy of the paper, and upon reading the article which concerned himself, he became angry and excited, because he did not know the things he said were to be published, and declared that he never made some of the remarks pertaining to Professor Benedict. He told the reporter that his action was dishonorable, and that if such reports were to be continued he would go to another paper with his story. It was then agreed that the paper should only publish what he himself wrote and signed.

After this the paper was not sent to him, and it was 5 days before he could obtain the copies. To his surprise and anger he found they had not published the best part of his stories, and had put in things that he did not write and which were detrimental to those in charge of the experiment. He again protested, saying it was not honest treatment, and finally refused to have anything more to do with the paper. The newspaper defrayed his expenses for 9 days, and then he went to the house of a fellow countryman in East Boston. After this he gave some lectures, and later was taken up by the Esperanto Society.

Later still a gentleman became interested in him, and offered to defray his expenses while studying medicine. At the present time, *i. e.*, date of this examination October 19, 1912, he is a student at the Harvard Medical School. Each morning on his way to the School he passes Professor Benedict's window in an automobile, which, he said, with much satisfaction, is the "irony of the case." He concluded his remarks by saying he had encountered a good deal of trouble with various persons he had come in contact with since arriving in America, but he felt now that for the most part it was due to misunderstanding.

MENTAL ATTITUDE OF THE SUBJECT TOWARD THE FAST.

The mental attitude of the subject was noted at each visit during the entire period of observation. The predominating idea with him throughout was that fasting is always beneficial. He believed that it is followed by physical and mental well-being in normal persons and is the rational treatment for diseased conditions. His own expressions were: "Food impedes the body and mind and animal food is poison. * * * I am anticipating the fast with much pleasure, as the poison of the food I have eaten will be eliminated, my body cleaned of its impurities, and my mind will be free and active. * * * The neurasthenia and depression from which I have suffered for years will leave me and I shall feel free and light and full of hope." Any dissent from these ideas was promptly resented with such a remark as: "My

dear doctor, you know nothing about fasting, while I have made it a scientific study." He considered himself an authority, qualifying the assertion by saying that he is now and always has been a student, that he has repeatedly fasted, carefully watching the effects of fasting, and that he has studied all the available writings upon the subject. He stated that his object in undertaking the present experiment was to accomplish the most complete fast yet undertaken, under the best scientific conditions possible to obtain, not for his own enlightenment, but to demonstrate to the world beyond doubt the truth of his theories. He said: "The experiment I am about to undertake will be of the greatest benefit to mankind."

Upon careful questioning it was learned that he had never undertaken a fast under strict scientific observation and that his reading had been in the main confined to non-scientific works, largely magazine articles.

On the occasion of the first visit it was evident that he was not only willing but anxious to assist in every way possible the work that was being done. He was very cheerful and was plainly pleased with attention shown him. This cheerful attitude continued for the first week. He was interested in what was being done and apparently tried to describe his subjective feelings with exactness. If any attempt was made to oppose his ideas as to fasting, his usual smile disappeared quickly and he assumed a sober, slightly injured air.

On the seventh day he appeared downcast, his movements were less active, and he was decidedly depressed mentally. He attributed this to the cloudy weather and rain and in so far as could be determined no other reason for the change existed. He expressed no displeasure at the manner in which the experiment was being conducted. On the ninth and eleventh days he was again cheerful, but not so enthusiastic as he had been during the first week, and he moved about as though he felt some physical fatigue. He admitted that he experienced muscular weakness. Any conversation, however, which was pleasing to him would arouse his enthusiasm for a short time. From this time up to the twenty-ninth day of the fast he was frequently depressed, but always courteous and ready to submit to the examination. On the days with sunshine he was always more cheerful, but at no time was he as enthusiastic as during the first week. He appeared to be slightly fatigued most of the time after the first week. His movements in preparing for the examinations were more deliberate, and any attempt to hurry him was politely resented. After the first week he gradually became more sensitive to discomfort and pain, complaining of any unusual pressure of the stethoscope or pressure of the hands in palpating the organs. He frequently spoke of the annoyance of the rectal thermometer and of the adhesive tape used in retaining the stethoscope on the chest wall. This annoyance was plainly shown in the expression of his face and in the careful manner in which he moved about when the

thermometer was in the rectum. During the periods of depression he was frequently disinclined to talk, and was sometimes irritable. At no time, however, did he object to the examination, and he always seemed willing to do whatever was necessary for the success of the experiment.

On the fifteenth day he said that his mind was beginning for the first time to become clear; on the nineteenth day he began to feel the desire to do mental work; and from this time on he declared that his mind was continually growing clearer. Certainly there was no outward evidence of the truth of this statement. He appeared fatigued mentally, and he neither understood nor answered the questions put to him so promptly as he did early in the fast. As far as could be determined there was no such stimulation for study as he had predicted. On the contrary he seemed to be less occupied with his books and papers.

On the last day of the fast he appeared to be very sober and assumed rather an injured air. His general attitude was a complaining one. The fast was being broken contrary to his judgment, as it was harmful to take food before the desire for food had returned. Then for the first time he complained of his medical care, saying that while the examinations were made in the most careful and painstaking manner no attention had been paid to his physical exercise and he had not been allowed to go out in the fresh air as much as he should have.

Nothing was observed at any time which would lead one to suppose that the subject experienced any sensation of hunger or any feeling of distress in the abdomen throughout the entire fast.[1]

Two hours after breaking the fast he was seen seated at a table where he was slowly eating his fruit juice and honey. His expression was downcast and his features drawn. His voice was weak and he spoke with deliberation. Notwithstanding his resentment at the breaking of his fast he willingly submitted to examination. He complained of pain in the abdomen and sudden spasmodic changes in his expression occurred at the time he said he was having pain. Palpation of his abdomen, however, only slightly intensified the discomfort.

Twenty-four hours after breaking the fast the general expression of depression was more marked. The voice was weak and he moved about very slowly. At this time there was no evidence of any physical discomfort other than lassitude.

On the third day after partaking of food he appeared in decidedly better spirits. There was no expression of discomfort and he smiled frequently during the examination. His movements were not so deliberate. He attributed his bad feelings of the previous days to the pain and discomfort he had suffered and did not appear to entertain

[1]Cetti on the fifth day of the fast complained of pain in the epigastrium from time to time, on the sixth day of belching gas and of distress in the abdomen, on the eighth day of severe abdominal pain, which disappeared on the ninth day after the bowels moved; on the tenth day he complained of feeling very weak physically and of being nauseated. No note is made of the gastro-enteric condition in the case of Breithaupt and Beauté.

such a strong feeling of resentment because he had been obliged to break his fast.

On the fourth day after taking food his mental attitude had entirely changed. He was very emotional, his voice scarcely audible. He wept as he talked. His hands trembled and his face was bathed in perspiration. He appeared weak physically, and while he made no objection to the examination, any undue haste or unusual pressure on the body made him complain. He evidently felt that he had not been given the proper medical attention during the entire period, although he had refused, at all times, to accept suggestion, except that he dilute his fruit juice. This was because "the physicians had no experience in fasting." He demanded that he be sent to a hospital, where he could get the attention he needed in his present sick, weakened condition.

The following morning, when visited at the hospital, his entire attitude had again changed. He was sitting on a veranda reading, and appeared delighted at seeing me. He was in a very cheerful state of mind, but was still emotional. He moved about quickly, showing none of the prostration of the previous day. He appeared to be very sorry that he had been so unreasonable at the laboratory, was apologetic, and expressed his willingness to return.

When seen five months after the fast was broken, he appeared rather unhappy. In telling his story it was evident that he had had differences with nearly every person he had come in contact with. He was plainly disappointed because the world had not given him the recognition due him for the sacrifice he had made for the benefit of mankind.

THE PSYCHO-PHYSIOLOGY OF A FAST.

By Herbert Sidney Langfeld,
Instructor in Psychology, Harvard University.

The subject of these tests was a man 40 years of age, of medium height and slender. When not in conversation his manner was languid and it is perhaps due partly to this that he seemed to lack physical strength and vigor. In temperament he was of the decidedly emotional southern type, sensitive, quick to anger, loquacious, credulous, and fertile in imagination. This last characteristic is probably responsible for the fact that the unusual appealed to him. Once having espoused a cause or entertained an idea, he would hold to it tenaciously. He was a man of a few fixed ideas or complexes, which formed the basis of his mental life.[1]

The tests herein described lasted from April 11 to May 15 inclusive.[2] Food was taken on April 10, 11, 12, and 13 and again on May 15. The intervening 31 days were fast days. The psychological tests were made at 5 p. m. each day and lasted 1 hour. During the half hour before the tests the subject rested.

The psychological tests were made under unusually accurate and complete control of diet and occupation. One factor important to mental measurement was found to vary, that is, the mood of the subject. As far as L.'s willingness to cooperate is concerned, there was nothing to indicate to the experimenter a change in this attitude or that his general interest in the work relaxed at any period of the series. On the other hand, there is no doubt that he was happier during the first part of the fast, rather depressed and silent in the middle, and somewhat irritable and excitable toward the end, although this irritation was at no time directed toward the tests. The greatest depression occurred after a prolonged continuation of bad weather and very much decreased after he was able to go out in the air. He was also much happier after having received visitors. He himself remarked that the monotony of the program was the most difficult thing he had to endure. As to his physical condition he made few complaints. He felt well throughout and insisted that he had no sense of hunger even during the first days.[3] The only discomfort of which he spoke was the coated con-

[1] An idea of his intelligence and interests may be obtained from the association reactions. See Appendix II, pp. 222–229

[2] The tests on April 11 were tentative and are not included in the curves.

[3] This is contrary to the experience of most fasters. W. B. Cannon and A. L. Washburn (An Explanation of Hunger, Am. Journ. Physiol., 1912, **29**, p. 441) describe the feeling of hunger as follows: "Hunger . . . is a dull ache or gnawing sensation referred to the lower mid-chest region and the epigastrium. It is the organism's first strong demand for nutriment, and, not satisfied, is likely to grow into a highly uncomfortable pang, less definitely localized as it becomes more intense." Further (p. 442): "There is abundant evidence, however, . . . that during continued fasting hunger wholly disappears after the first few days." Professor Cannon has recently informed the author that from what certain fasters have told him he believes that sensations of hunger may be absent from the beginning; that in fact some people may never have the sensations of hunger as just described.

dition of his tongue and the unpleasant taste in his mouth. It was his idea that the fast should continue until this disappeared and it was for this reason that he was loath to break his fast on the thirty-first day.[1] Although he seemed more feeble toward the end of the fast and gave one the impression of a man convalescing from a weakening illness, yet he was always able to walk without assistance and at no time was it necessary to omit or alter a test through lack of strength on his part. On May 15, the day he broke his fast, he suffered severe colic, induced by the food he ate, and although tests were made the conditions were most unfavorable. It had been planned to continue the examination for several weeks longer, inasmuch as such tests would obviously be of inestimable value for comparison with the fasting tests. Unfortunately that was quite impossible under the circumstances and an entire year elapsed before further records could be obtained.

Several factors influenced the selection of the tests. In the first place the time was limited. There was only 1 hour daily available and it seemed advisable to arrange for as many tests as possible during this hour in order to obtain a good mental picture. It was therefore necessary to choose short tests and also those requiring the minimum of effort, as one test had to follow the other without pause for recuperation. For example, prolonged tests for fatigue would have been of great value, but they could not be considered. In the second place, the fasting began a few days after L.'s arrival and little time could be devoted to preliminary trials in order to obtain the best combination, and the program once arranged could not be fundamentally changed.[2] After consultation with Professor Raymond Dodge, a series of tests were selected. A few days' experience, however, showed the necessity of several alterations, and the revised program was as follows: (1) Rote memory for words; (2) tapping test; (3) strength test; (4) tactual-space threshold; (5) touch threshold; (6) free association and reproduction reactions; (7) association reactions, genus-species; (8) association reactions, noun-verb; (9) cancellation test; (10) hand-writing;[3] (11) visual acuity; (12) memory for words after 55 minutes. Later the touch threshold, which was taken on the under part of the lower forearm with a von Frey hair, was discontinued on account of the impossibility of obtaining reliable results in a short period of time. The association reaction genus-species was also omitted through difficulty in finding sufficient reaction words of equal simplicity. In addition to the tests L. was requested to describe all the dreams he had on the previous night.[4] This was given before the visual acuity test. All the

[1] Thirty days were considered sufficient for the physiological tests and he was allowed one day more to excel Succi's record.

[2] A few minor changes were introduced.

[3] A superficial examination of the daily records revealed no change. A systematic examination of the data has not yet been made.

[4] See Appendix I, p. 222.

tests with the exception of that of visual acuity were made in a small room free from disturbing influences.[1]

The general conditions of the experiments and the nature of the tests having been described, each test will now be treated separately, first as to the particular conditions and second as to the results.

MEMORY FOR WORDS.

Ten one-syllable words were chosen and these were read twice to the subject, who recalled as many as possible immediately after the the second reading. After 55 minutes the subject again attempted to recall these words.

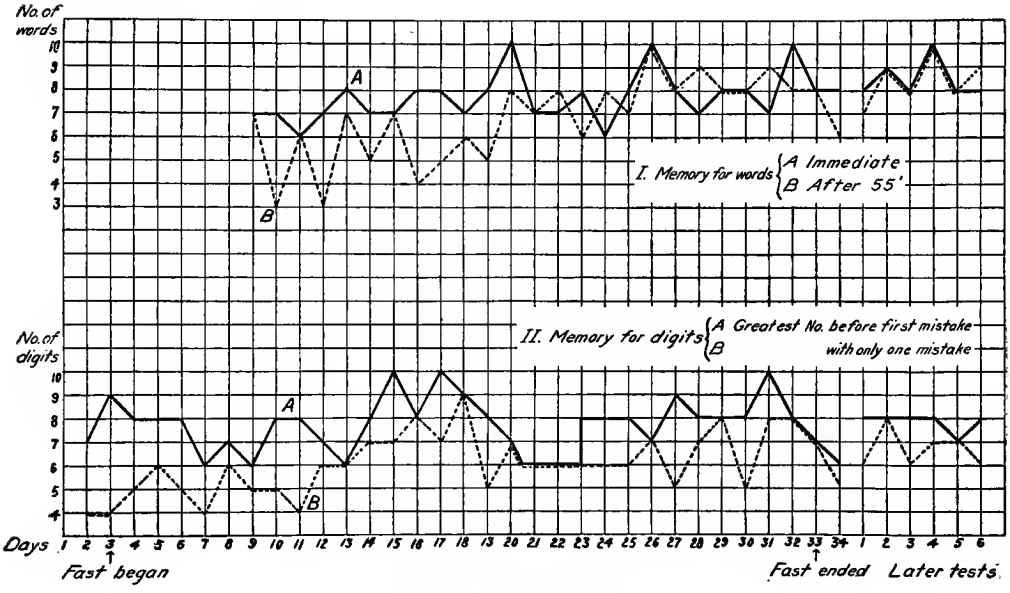

FIG. 23.—Memory tests.

From the curves (figure 23) it will be seen that there are marked fluctuations, a circumstance which is always met with in mental tests and which will be found in all the curves. It will therefore be only possible to speak of general tendencies throughout. In the curve for immediate rote memory (A) it will be seen that the poor record made on the eleventh day (the third day of the test) only occurs once again, and that on the twenty-fourth day, while a perfect score of the 10 words was made 3 times and all of them during the last two-thirds of the fast. It can be said that although the early records reoccur frequently toward the end, yet the curve as a whole shows a slight general improvement, but so slight that not much significance can be attached to it.

[1]It is much to be regretted that time and conditions prevented tests for the threshold of audition and smell.

The curve B, indicating the amount of retention after 55 minutes, on the other hand, shows a more or less steady improvement until near the end of the series, and even when these last trials are included the general tendency of the curve is decidedly upward. In 4 instances, and these all in the last two-thirds of the series, the retention curve crosses the rote memory curve, which means that on these days the retention after the lapse of almost an hour was better than the immediate memory. L., upon being questioned, was emphatic in his assurance that he never thought of the words in the interim, so that this relative improvement in retention was not due to any conscious repetition during the pause.

TAPPING TESTS.

The instrument used was similar to the tapping-board described by Whipple.[1] It consisted of a board 12 cm. square and covered with aluminum. This metal is not very well adapted for the tapping-board, but it was selected for its lightness, it being thought quite probable that the tests would have to be made toward the end of the experiments with the subject lying down and the board resting on his chest. The stylus also had an aluminum point. The records were taken on a kymograph. The tapping lasted for 30 seconds and periods of 10 seconds were marked off on the records. The subject being left-handed used that hand. As he was over-sensitive to cold during the fast he wore, besides a heavy woolen undershirt, a heavy dressing-gown, which added to the weight he had to lift. Neither the hand nor arm was allowed to rest on the table during the tapping.

Curve III (figure 24) shows a gradual improvement for the first 6 days, when the maximum of the series—215 taps or about 7 taps per second—was reached. The curve then descends for the next 9 days, when the minimum of 170 taps was reached. From this point to the end of the series there is a rise to a point just below the maximum. This rise is not, however, gradual, but consists rather of 2 plateaus, one of 9 the other of 7 days, separated by decided jumps and followed by a gradual but very marked end spurt of 4 days.

The initial improvement can well be due to practice in using those particular sets of muscles, combined with increasing familiarity with the work. This same rise also occurred in the dynamometer tests. The drop, however, begins much sooner than in the dynamometer tests. In fact, it ends in the former where it begins in the latter. One can therefore hardly say that it is a matter of muscular fatigue. The first explanation to suggest itself is a lessening in interest, and this is strengthened by the fact that the drop occurs at that time when he was most affected by the monotony of the routine work. In this test less depends for improvement upon the increase in muscular power than

[1]Whipple's Manual of Mental and Physical Tests, Baltimore, 1910, p. 101.

in the dynamometer tests, the main factor being the rapidity of action. We know that the rate of the reaction time is greatly affected by changes in attention, and it is probable that the betterment in the muscular control, which we may assume from the results of the dynamometer tests did occur, was insufficient to offset this loss of interest. The results of the last days confirm this assumption, for here we undoubtedly have the effect of interest in an end spurt, which, notwithstanding the muscular fatigue undoubtedly present at this time, brings the curve back to a higher level. In regard to the two plateaus referred to above, it seems plausible to infer, from what we know of the causes of plateaus in the learning process in acts of skill, that these sudden

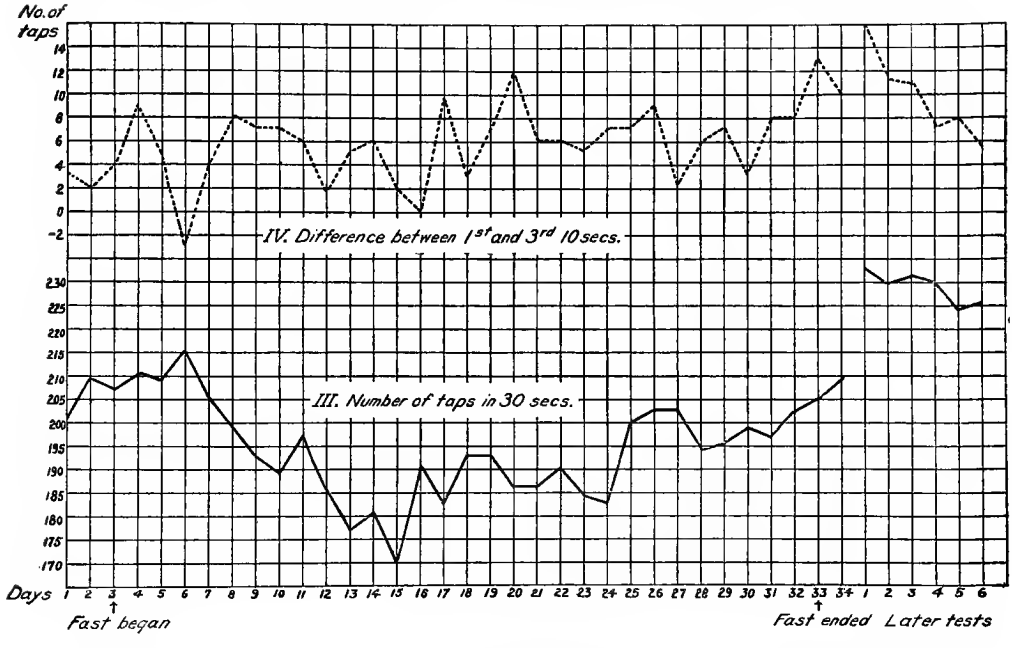

FIG. 24.—Tapping tests.

rises to new levels are due to the learning of some new method or short cut. Here the most obvious short cut is the lessening of the height of the stroke.[1]

An examination of the difference curve (IV, fig. 24), which has been obtained by subtracting the result of the last 10 seconds from that of the first 10, still further confirms the assumption of a wavering in interest. There is a gradual increase in the amount of this difference, which indicates fatigue. This increase is particularly marked toward the end, when the records are improving, which means that the improvement is caused by a spurt during the first 10 seconds.

[1]This is an error which is bound to occur with this form of tapping-board. The writer has therefore, recently constructed a board which regulates the height of the stroke, thus making it a constant factor.

In general, it may be said that although initial lack of interest[1] and later muscular fatigue played a role, both factors being directed toward a decrease in the amount of work, yet the will impulse toward the end was sufficiently great to bring the curve back to its initial level and almost to its maximum.

STRENGTH TESTS.

These tests immediately followed the tapping tests. The subject stood and received the dynamometer, one of the Collin type, from the experimenter, and pressing it, returned it to the experimenter. The record was noted and the instrument returned. The interval between trials was about a second. Ten trials were made with the left hand,

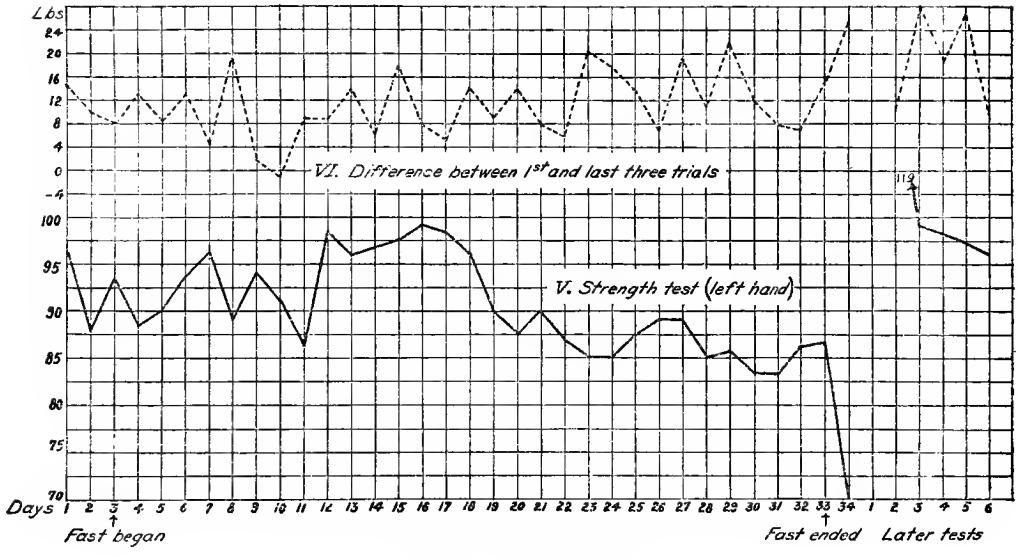

FIG. 25.—Strength tests.

followed by ten trials with the right. Both in the right-hand (VII, fig. 26) and left-hand (V, fig. 25) curves there is an initial falling off, which is more marked with the right hand. The left-hand curve, however, continues to fall to the tenth day, when it takes a decided drop, while the right-hand curve declines more gradually to the ninth day, when it reaches its minimum. Both curves then rise to a maximum, which is reached by the left hand on the sixteenth day and by the right hand on the twelfth day (the record of the first day not being considered in speaking of this maximum). The curves then fall, the left much more than the right, especially in the middle of the series, the former reaching its minimum on the thirty-first day. Both

[1]Against this suggestion is the fact that other tests did not show this lack of interest, but it is quite possible that the interest varied with the different tests.

curves show a slight end spurt. This is, as a glance at the curve will show, merely a rough picture, there being decided rises and falls throughout.

In interpreting the curve it must be remembered that L.'s left hand is the practiced hand and it can therefore be assumed that the muscles of that hand are the stronger. In fact, the results make this more than an assumption, for the record of this hand is at all times decidedly better than that of the right hand. The initial falling off is what one must expect when the subject is not accustomed to the particular muscular exercise. There is a great exertion at first, and the muscles, skin, and subcutaneous tissue feel the unusual strain for several days. The muscles least accustomed to exercise are the most affected, and

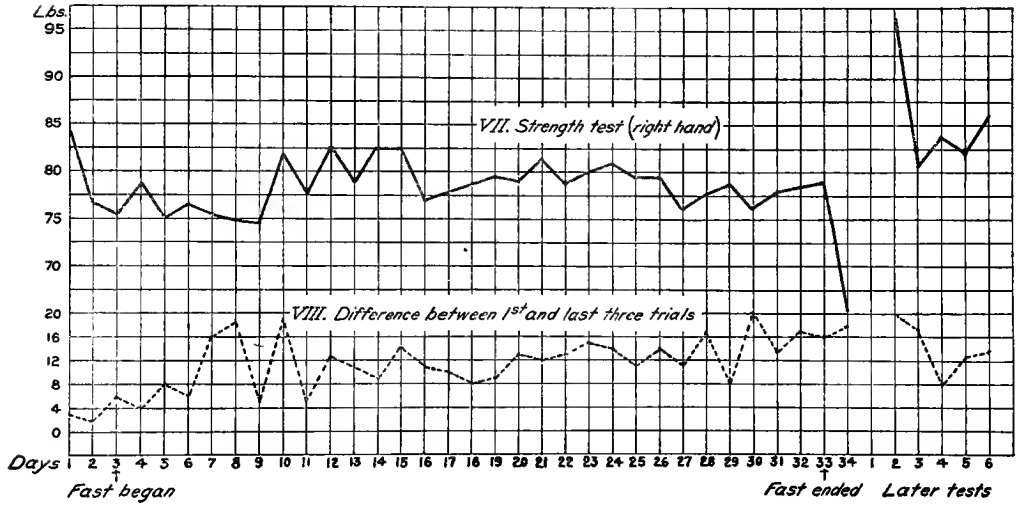

FIG. 26.—Strength tests.

for this reason the right-hand record drops more than that of the left hand. Then the muscles gradually recover and the effect of practice begins to appear. Acting against the practice is the increasing fatigue. The right hand being the unused hand gives practice more chance for its influence and although fatigue never allows the curve to reach its first day's record, yet the drop which soon begins is much more gradual, as has been pointed out, than it is with the left hand, which shows more clearly the effect of fatigue.

The difference curves (VI and VIII), which were obtained by subtracting the average of the last three records of each day from the average of the first three, help to strengthen the conclusions just drawn. The rise of the difference curve at the same time as the fall of the main curve means, of course, increasing fatigue, which shows itself in a greater and greater drop toward the end of the daily series.

This rise in the two difference curves is relatively about the same, which means that the daily increase in fatigue is relatively the same for the two hands. Further, if we glance at curves IX and X, fig. 27, we find additional indications in the same direction. This curve is plotted from the first of the daily series of 10 trials. This trial is least affected by fatigue and therefore shows the greatest influence of practice. Here there is a gradual rise for the right hand until next to the last day, while the curve for the left hand begins to drop where it should according to our analysis.

In general, we may therefore say that fatigue appears in both hands early in the series. The curve for the left hand drops far below the record of the first few days. The curve for the right hand shows less drop, due to the greater influence of practice, so that the two curves tend to approach one another.

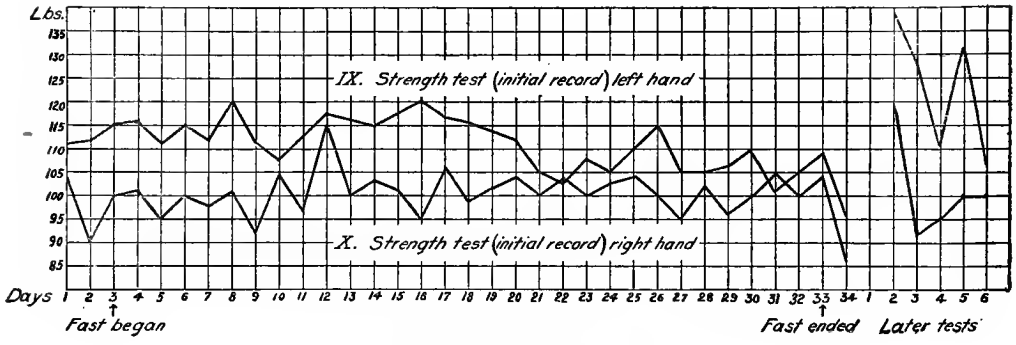

FIG. 27.—Strength tests.

TACTUAL-SPACE THRESHOLD.

A pair of dividers with wooden tips were used as an æsthesiometer. The threshold was found on the volar side of the forearm, about 4 inches from the elbow. The points were applied on either side of a red-ink dot which was made on the arm on the first day and renewed when necessary. The method of minimal change, with ascending and descending series, was employed; 5 trials, excluding one-point "vexier" trials, were made at each distance; 4 correct out of 5 was considered the threshold.[1]

For the first few days the curve (XI, fig. 28) keeps the high level of 7 cm. On the seventh day there is a drop to 5.5 cm., then a slight rise to a level of 6 cm. and a high threshold of 6.5 cm. on the fourteenth day, followed by a fall to the minimum of 5 cm. on the twenty-second day, which minimum is again reached on the twenty-sixth and thirtieth

[1]It had been intended to call 3 out of 5 the correct threshold, but this was not found feasible. The threshold is probably too high, but for the present purpose, where the change and not the absolute threshold is being investigated, this does not matter. The curve shows no record for the fourth and fifth days. The experimenter was absent on these days and the physician who kindly volunteered his services did not deem himself sufficiently skilled in this particular test to undertake it.

days. The final days show a rise to 6 cm. The decided drop on the seventh day may be due to adaptation to the experiment, which in this instance means the adoption of a definite and clear criterion of discrimination. The drop in the middle of the series, after a more or less constant level, may be due to a similar cause—that is, a change to a better criterion. The rises in the latter part of the curve are never as great as those of the first part, although on the last day the curve again reaches 6.2 cm. This threshold had to be placed at 5 correct judgments, as there was a jump from 3 correct judgments. This makes the threshold probably too high. If we omit the first day and compare the average of the period from the seventh to the twentieth day with the average of that from the twenty-first to the thirty-fourth day we find a difference of 0.4 cm. in favor of the latter period. We may say

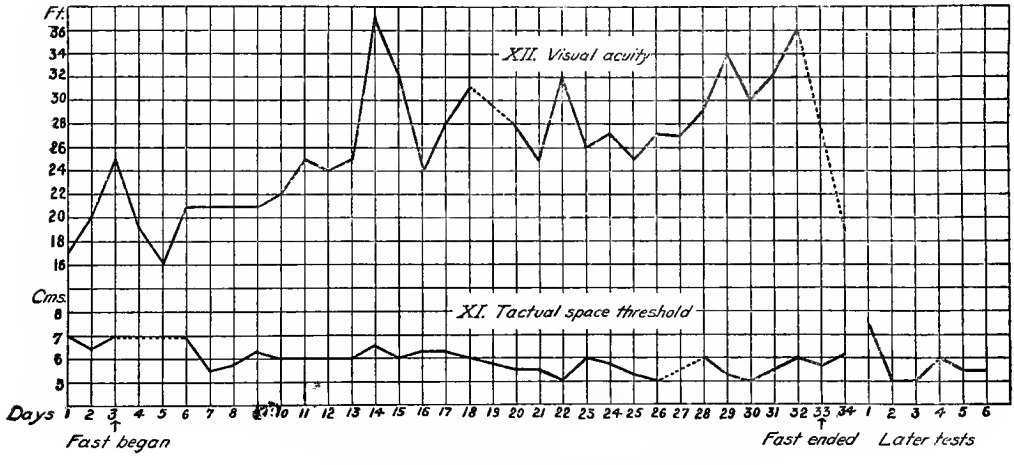

FIG. 28.—Tactual-space threshold and visual acuity.

then, in general, that there is a very slight improvement in the discriminating process, but that there is no end spurt, which latter, from the very nature of the process under investigation, is not to be expected.

ROTE MEMORY FOR DIGITS.

The usual rote memory test was employed. Increasing series of digits, beginning with 4 digits, were read aloud once by the experimenter to the beat of a metronome with 1-second intervals and were repeated as far as possible by the subject. The combinations of digits varied daily.

Curve II B, fig. 23, is obtained by taking the last series that contains only one mistake, curve II A, fig. 23, by taking the number which immediately precedes the one containing the first mistake. Curve A, which gives a picture of the rote-memory process, shows two apexes of maximal value near the middle and another on the thirty-first day.

There is, however, a very low minimum in the second half of the curve and a decided drop from the maximum of the thirty-first day. One can, therefore, hardly speak of an improvement. The most that can be said is that toward the end of the fast the subject was again able to reach the maximum record of 10 digits obtained near the middle of the series. From curve B we see that on the third day a mistake was made at 4 digits, yet the retention is 9 digits; on the eleventh day a mistake at 4 digits and a retention of 8, etc. It seems fair to assume from these results that curve B represents in a rough manner the degree of attention. It is only inattention that can produce results like the above. Curve B shows a decided rise to the eighteenth day, when it reaches a maximum, and although it follows a lower level from this day it never reaches the minimum of the first third of the series. One may therefore say that there is an improvement in the state of attention, at least for this experiment, as the fast progressed.

ASSOCIATION TESTS.

The free-association experiments consisted of the daily presentation of a list of 20 words, which were selected principally from the lists prepared by Woodworth and Wells,[1] and with the exception of the list of May 9, which was a repetition of that of April 11, they were all different.[2] Several days after the tests were begun it was thought advisable, in order to make the lists as uniform as possible, to have them composed of an equal number of verbs, concrete nouns, adjectives, and abstract nouns, in the order given. This arrangement was adhered to from April 18 to the end of the tests, with the exception of May 9. The words were read aloud by the experimenter and the time taken with an ordinary stop-watch. The reproduction experiments followed these with only a pause of a minute. Although the subject was told that he need not repeat the same word, if it did not come at once, yet there is little doubt that his efforts were always directed toward that end. L. had a good command of the English language, although it is not his native tongue, but at times he had difficulty in finding the word he wanted. In such cases he made a gesture as soon as the idea came to him and the watch was snapped at that time rather than when the English word was found. This method of procedure was not often necessary and it seemed a legitimate means of balancing the slight disadvantage he had as a foreigner. A reserve list was prepared upon which to draw when he did not understand the word of the main list.

The curve (XIII, fig. 29) is plotted from the daily average. The average was used in order the better to include the influence of the

[1] Woodworth and Wells, Association Tests, Psych. Monog., 1911, 3.

[2] The lists will be found in Appendix II, pp. 222-229. In a few instances the same word appears in two lists.

long times, which might very well be of importance in these tests.[1] The few exceptionally long times, such as 20 seconds, which may have been caused by emotional complexes, were not included.

The curve begins with very long reaction times. L. had never performed such tests before, so that the sudden drop on the third day

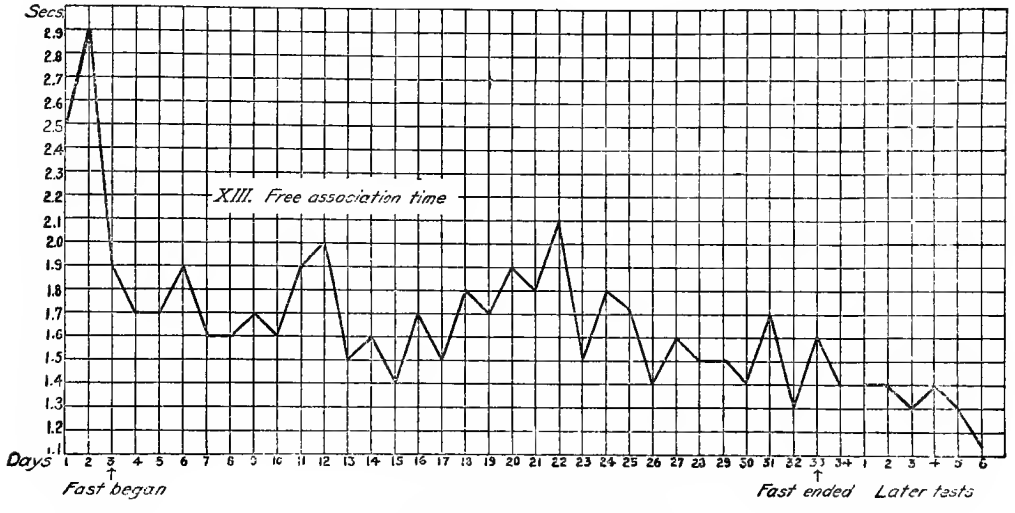

FIG. 29.—Free association tests.

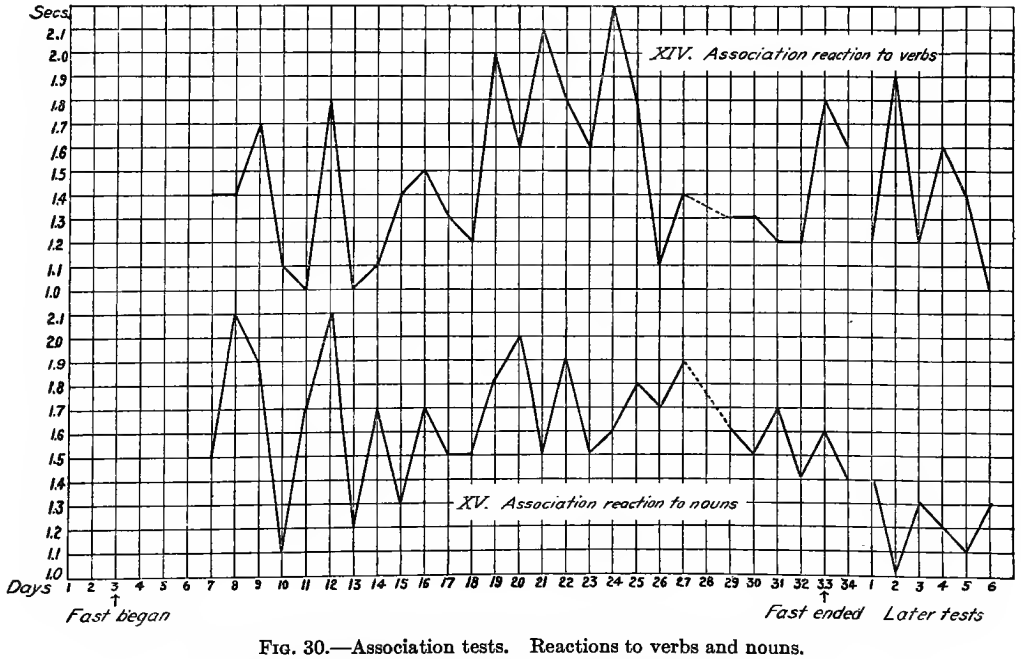

FIG. 30.—Association tests. Reactions to verbs and nouns.

[1]The median, which was also calculated, gave the same general curve.

must be attributed to the practice improvement, which at this early stage could very well be sudden and of considerable amount, rather than to the fact that it is the first day of the fast. From this point the curve descends with a few breaks to the fifteenth day, when it reaches 1.4 seconds; it then rises to the twenty-second day, when it reaches the maximum (if we do not consider the first few days) and then falls to the end of the series. On the second from the last day it reaches the minimum of 1.3 seconds. Also the record of 1.4 seconds is obtained 3 times

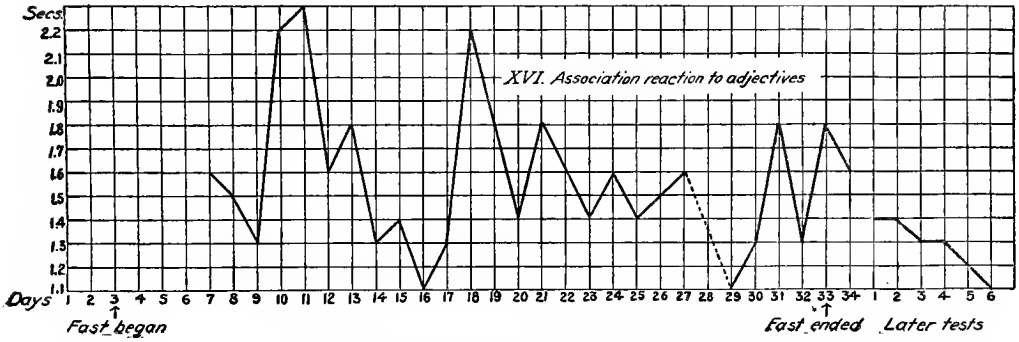

FIG. 31.—Association tests. Reactions to adjectives.

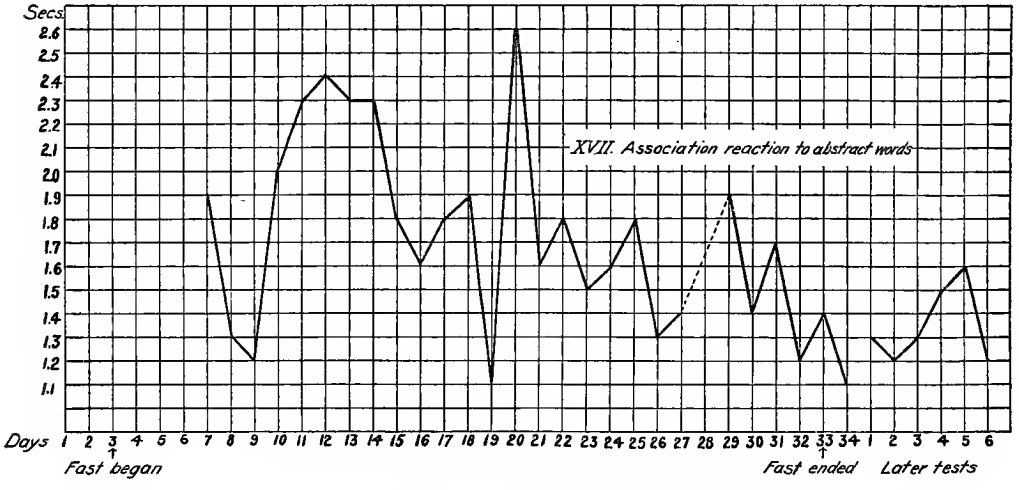

FIG. 32.—Association tests. Reactions to abstract nouns.

in the second half of the series. If we include the first few days it can be said in general that there is a very decided betterment in the association times; and even if one calculates from the third day there is an appreciable drop. Especially interesting is the almost steady improvement shown in the last third of the curve.

In order to analyze the curve further, separate curves (XIV, XV, XVI, and XVII, figs. 30 to 32) have been plotted for each of the four

categories of stimulus words. It must be remembered that these curves begin on the seventh day, when this division into separate categories was first made. In consideration of the fact that the daily average is obtained from only 5 reactions, too much importance must not be attached to sudden daily falls and rises, such as in the abstract series on the nineteenth and twentieth days and in the adjective series on the eighteenth day, etc., but rather the convex shape of the verb curve, the rise in the middle of the noun curve, etc., must be considered.

It is evident that the rise in the main curve about the tenth to thirteenth day is caused largely by the noun curve and that the relatively greatest improvement at the end of the curve as compared with the

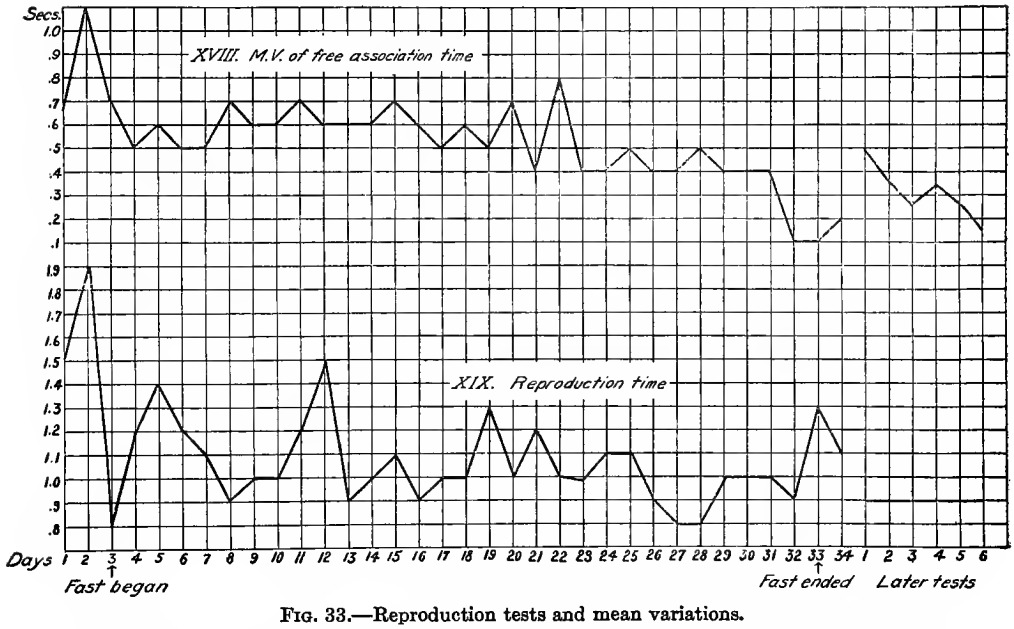

FIG. 33.—Reproduction tests and mean variations.

beginning is in the abstract curve. On the other hand, the verb and noun curves have several low averages in the beginning that were not reached again. In fact, it is hardly possible to say that either of these curves shows general improvement; certainly not the noun curve. An examination of the daily fluctuations in the curve shows that the fluctuation becomes less as the tests progress.

The curve (XVIII, fig. 33) for the mean variation of the main curve shows a decided improvement as the fast progresses, with a very low level on the last 3 days.

The reproduction curve (XIX, fig. 33) follows the tendencies of the association curve. There is the initial drop and many more high peaks in the first two-thirds of the series. If it were not for the rise on the last two days the general betterment would be more marked. The reac-

tions were, on the whole, rapid, averaging about 1 second and dropping as low as 0.8 second. As the number of false reproductions was very small (see I, table 21), amounting to only 23 in 680 reactions, or 3 per cent, and never more than 3 in one list, an improvement or the reverse in this respect would mean little. At least one can say that the quality of reproduction suffered no deterioration with the progress of the fast, but that retention was equally as good at the end as at the beginning.

TABLE 21.—*Qualitative analysis.*

No. of test.	I. False reproductions.	II. Classification of reaction words in association experiment.					III. Mistakes in cancellation test.	
		Misunderstood.	Identity.	Perseveration.	Repetition.	Word compounding.	Omissions.	Incorrectly crossed.
1st....	1	..	..	..	1	..	0	1
2d.....	2	1	1	..	..	..	1	0
Fast began.								
3d.....	3	1	..	..	..	..	0	0
4th....	1	..	..	..	..	3	2	1
5th....	2	..	1	..	..	..	3	0
6th....	0	..	1	..	..	1	2	0
7th....	0	..	..	..	3	..	1	0
8th....	0	..	1	..	..	..	1	0
9th....	0	1	..	..	..	..	2	0
10th....	1	..	1	..	..	..	3	2
11th....	1	..	..	..	..	..	2	1
12th....	1	..	1	..	..	..	0	0
13th....	0	..	..	..	..	..	2	1
14th....	0	..	..	..	1	..	1	0
15th....	1	..	..	..	..	..	0	0
16th....	0	..	..	..	..	2	1	1
17th....	0	1	..	..	..	1	1	0
18th....	0	..	..	..	..	..	4	0
19th....	0	1	..	1	..	1	1	1
20th....	2	..	2	..	..	..	0	0
21st....	1	..	1	..	..	2	0	0
22d.....	2	..	..	..	..	..	0	0
23d.....	1	..	..	..	1	..	1	0
24th....	0	1	..	..	..	..	1	2
25th....	0	..	..	..	..	..	0	0
26th....	1	..	2	..	..	1	1	1
27th....	0	..	1	..	..	..	3	0
28th....	0	..	1	..	..	1	1	1
29th....	0	..	1	..	..	..	0	0
30th....	0	..	..	..	..	..	1	1
31st....	0	..	..	..	..	..	0	0
32d.....	0	..	1	..	..	2	0	0
33d.....	2	..	2	..	1	..	4	1
Fast ended.								
34th....	1	..	2	..	..	..	0	0
Later tests:								
1st....	0	..	..	..	1	1	4	0
2d.....	0		3	..	..	..	1	0
3d.....	0		1	..	1	..	0	0
4th....	0	..	..	1	..	..	..	..
5th....	1	..	..	2	1	..	0	0
6th....	0	..	..	1	1	..	1	0

The quality of the association reactions was of high grade throughout the main test (II, table 21). There were no senseless or pure sound reactions and very few repetitions. Synonyms, word-compoundings, and misunderstood stimulus words occurred seldom and were scattered throughout the days. The word "woman" appears a number of times and "man" slightly less often. There was also evidence of a religious complex. An examination of the different categories did not show sufficient change to warrant an analysis or tabulation as to quality. It was thought that the introduction of words designating food might produce delayed reactions both with the word itself and the words immediately following. This was not the case. For example, on April 16 we find egg-white 1.4 seconds; on April 19 omelet-eat, 1.4 seconds; on April 21 fish-sea, 1.4 seconds; on May 7 candy-sweet, 0.8 second; on

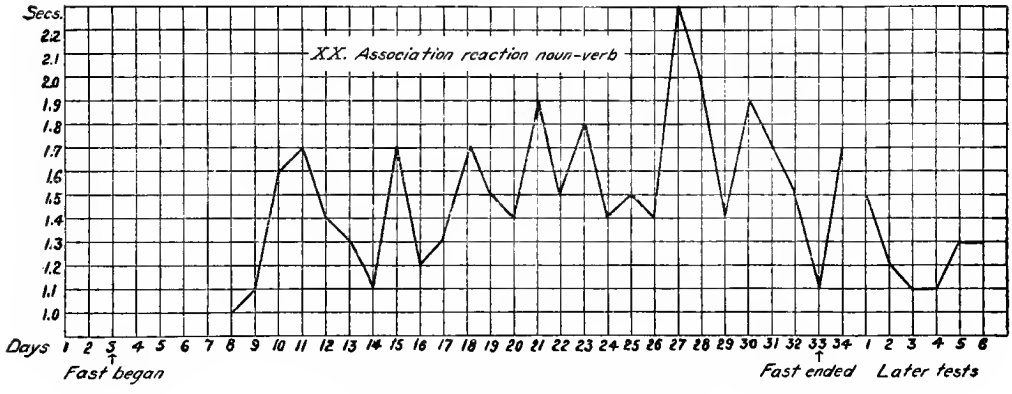

FIG. 34.—Controlled association tests.

May 9 apple-fruit, 0.8 second; on May 10 roast-meat, 1 second; on May 13 chocolate-sweet, 1 second. None of these reactions were followed by unusually long reaction times. It might be of interest to mention at this point the unusually long reactions which point to complexes. On April 13 we find pulse-hand, 9 seconds; on April 21 death-eternal, 22.4 seconds; and on April 26 uncertainty-pendulum, 12.6 seconds. These are the only extremely long reaction times. The next longest is 6 seconds. All of these delayed reactions may be explained from the same cause. L. had asserted that the chief factor for a successful fast was faith and confidence and absolute lack of fear. He thinks it is the fear combined with exposure which causes death in shipwrecks and other calamities where food is not obtainable, and not the actual lack of food. It is also claimed that those who fast frequently cover their mirrors in order that they may not be disturbed by the evidences of emaciation. One of the supposed dangers in fasting is heart failure. If L.'s heart had shown alarming symptoms the fast would have been terminated at once. It does not, therefore, require

a stretch of imagination to suppose that L. would keep his mind from such subjects as death and uncertainty and that he would even avoid thought of the condition of his heart and that the mention of these words would cause hesitation.

The determined association reaction noun-verb was begun on the eighth day. Curve XX (figure 34) resembles that of the verb curve, except that the rise continues longer. It starts very low (1 second), increases with rather large daily fluctuations, and on the last day of the fast returns to 1.1 seconds. A particularly disturbing factor in this series was the fact that there was an ever-increasing difficulty to obtain appropriate words. At first the words had obvious associations. They were names of common objects, such as dog, gun, eye, etc., but more unusual words had to be employed in increasing numbers, and there seems no doubt that this circumstance was at least partly the cause of the increasing length of the reaction time. It is even more important in the determined than in the free-association experiments, to have the quality of the words the same and not more difficult. For long series of tests the free-association experiments are much to be preferred.

CANCELLATION TEST.

Special forms were made for this test, consisting of type-written pied text of 100 a's and 50 of each of the other letters of the alphabet. A different combination was made each day, so that the subject should not become accustomed to the order. L. was requested to cancel all the a's. He used his left hand and the time was taken with a stop-watch. Special care was observed to have the illumination constant and the same pencil was employed.

The curve (XXI, fig. 35) represents the time for the completion of the task. As in some of the other curves, so here we have the initial rise, which continues to the sixth day, when there is a sudden drop to a level which slopes slightly to another sudden drop on the twenty-ninth day and a very low level for the final days. The difference between the maximum of 3 minutes 48 seconds on the sixth day and the minimum of 1 minute 53 seconds on the last fast day is very considerable. The maximum is over double the minimum, and even if we compare the minimum with the initial time of 3 minutes 7 seconds or with 2 minutes 43 seconds of the seventh day, which is the first and largest practice drop, we still find a very considerable difference. There does not seem any doubt, therefore, that there is very much of a betterment in the time as the fast progresses and that this decrease in the time continues to the end of the series. Nor is this improvement in time gained at the sacrifice of accuracy. At no time were there many mistakes made (see III, table 21). In fact, the degree of accuracy was always so high that we can not place any importance on the slight

increase of accuracy in the last half of the series[1] nor does the slight loss of accuracy at the minimum alter the significance of that result.

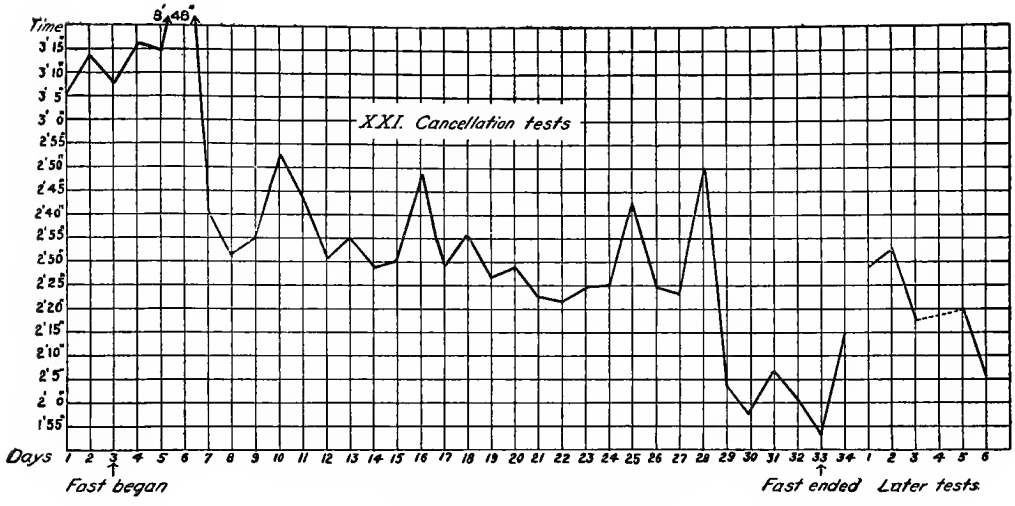

FIG. 35.—Cancellation tests.

VISUAL ACUITY.

These tests were made in the large calorimeter room adjoining the small room in which the previous tests were conducted. The largest E which had been cut from the Schnellen test-card was used. This was held by the experimenter at the level of the subject's head when seated. It was illuminated by an electric lamp held by a second experimenter in front of the card and moved with it. The shades of the room were kept drawn during the experiment in order to have constant illumination as far as possible. The subject suffered from myopia and wore corrective glasses. A distance was first chosen well within the threshold at which the subject was asked to judge in what one of the four possible positions the E was being held. The experimenter put the card behind his back when he changed its position. After a few days of the tests it was thought that the subject might be using the secondary criterion of the distance of the edge of the E from the edge of the card, the E not being exactly in the middle. The card was therefore mounted on a larger cardboard of the same color in order to obviate this possibility. On account of the surprising results, both experimenters were at all times keenly attentive to the possibility of other secondary criteria, but none could be discovered. Ten trials were made at each distance, the card being moved from the observer in steps of one foot. That distance was considered the threshold which preceded the distance at which the subject made two mistakes

[1]There were 29 mistakes in the first half and 24 in the second half of the series.

out of the ten trials.[1] The alteration in the position of the E followed no definite order, but every means was used in this respect to confuse the subject in order to remove all possibility of his guessing the position. Most of the judgments were made without hesitation, both at the very low and very high thresholds.

The curve (XII, fig. 28) represents the daily threshold in feet. There is a very rapid rise from the fifth to the fourteenth day, when the maximum of 37 feet is reached. Then there follows a drop to 24 feet and a rise to 36 feet on the next to the last day of the fast. The thirty-fourth day shows a drop to 19 feet. The record of the fifth day is 16 feet, which is the minimum; that of the thirty-second day is 36 feet, which is 1 foot less than the maximum. This difference of 20 feet is very great for visual acuity. He saw twice as far at the end of the fast as he did at the beginning.

LATER TESTS.

Owing to an attack of colic resulting from the nature of the first food taken after the fast and the subsequent withdrawal from the laboratory, it was impossible to continue the tests during the recuperative period, as had been planned. Only by later tests for comparison could a decision be reached as to the efficacy of fasting. One year after the tests just described L. volunteered as subject for a short series of tests. These were conducted at the Harvard Psychological Laboratory and extended over a period of 6 consecutive days. It was not possible to arrange for them to take place at 5 o'clock as previously and 10 o'clock in the morning had to be chosen. All the other conditions were observed as closely as possible. The same tests, with the exception of the visual-acuity test and the hand-writing test, were performed. L. seemed in good health. He weighed about 126 pounds, which is somewhat less than he weighed when he began his fast. His physical appearance was, however, very much the same as on the day he arrived at the Nutrition Laboratory. He had remained in America during the previous year, engaged in medical studies, lecturing, etc., had not fasted again, and had had no illness during that time. In coming to the laboratory he made a journey of 4 miles and had already had several hours' work, having risen each day at 5 o'clock, exercised for half an hour, and made several visits. The conditions previous to the tests are, therefore, hardly comparable to those of the former series. It is evident, however, that he was as strenuous, if not more so, than he had been up to the later hour of 5 o'clock of the previous tests.

The rote memory for digits (II A) was somewhat poorer than it was during the latter part of the long series. It did not reach the maximum

[1]Lack of time prevented the threshold being taken in the reverse direction. The tests took 5 to 10 minutes.

by two numbers, yet it did not show any poor scores. The curve (II B) which represents the first mistake, or, as it was supposed above, the state of attention, shows an improvement over the latter part of the first series in that it does not drop so far. On the other hand, the rote memory for words (I A) seemed as good if not better than during the fast. It reached the former maximum on the fourth day and never dropped below eight words. The memory after 55 minutes (I B) was as good as the immediate memory. From these results it may be concluded that the memory was still, after the year's interval, at about the level that it was at the end of the fast.

The curve (III) for the tapping begins considerably higher than the maximum of the fasting tests, and although it drops somewhat, still it remains above the former maximum. The drop in the difference curve (IV) is caused principally by a falling off in the initial spurt. This is concluded from the fact that the results of the last 10 seconds vary much less than those of the first 10.

The results of the first day of the tactual space threshold can not be utilized as a comparison (XI). The unusually high threshold was undoubtedly caused by inattention on the part of L., who admitted that he had been very much worried over an appointment he had been forced to miss and upon which his mind had been during these tests. Apart from this day the curve has the same form it had during the latter part of the previous trials. The second and third days show the minimum, which was last reached on the thirtieth day of the former trials.

The dynamometer used in the previous tests could not be obtained until the second day. There are, therefore, only 5 records. The curves for both the right hand (VII) and the left hand (V) begin with very high records and drop considerably on the second day, just as they did in the former series. These first records are very much better than any made in the previous trials. Even after the drop the right hand twice surpasses the previous maximum and remains close to it on the other days. The difference curves (VI and VIII) show that on the first day the high record for the left hand was made by a sustained effort. The right-hand spurt caused fatigue toward the end. The large differences during the next 3 days for the left hand were caused by spurts followed by fatigue, that of the right hand by fatigue. It is seen that the strength of the muscles of the hand had very much increased since the end of the fast, and judging from the first day's results was much greater than at the beginning of the fast. One acquires a knack in gripping the instrument and it may be that this was carried over from the former tests and made these initial records higher than those of the year before. In other words, some of the effect of practice was still present and influenced the results much more than it did when it had the opposing effect of fatigue.

The free-association reaction time (XIII) begins at the low point of the last day of the previous series; on the third day it reaches the shortest time of that series, and again on the fifth day and on the last day it falls almost one-fifth of a second below this point. That is, the curve continues the descent it began in the middle of the former series in as regular a manner as if a year had not intervened. Inasmuch as some practice was necessary after so long an intermission, it may be said that the reaction times were better than they were at the end of the fast. The m. v. (XVIII) was 0.5 second on the first day and 0.15 second on the sixth, with an almost steady decline.

The average reproduction time (XIX) is 0.9 second for all the days; this is very low, and although 0.8 second was reached 3 times in the former tests, it is safe to conclude that the reproduction times are at least as good as they were at the end of the fast. In fact, the average for these days is better than for any 6 consecutive days of the previous tests. There was only one false reproduction and that was "wrong" for "bad." In view of the fewness of the trials little would be gained by an analysis of the results according to categories XIV, XV, XVI, XVII. The noun and adjective curves are lower than the verb and abstract curves. The quality of the reactions is about the same. Evidence of a religious or mystic complex is as plain here as in the previous results. "God" was the reaction for "adore," "worship," "unseen," "mercy," "Divine," and "Infinite;" "supreme" gave "Being," "sacred" gave "church," "adorable" gave "saint," "life" gave "eternal," and "ornament" gave "church." There were no very long reaction times. In connection with the previous complex it may be mentioned that "death" was the reaction word for "fear."[1]

The reaction noun-verb (XX) begins at the average of the thirty-second day of the former series and on the third and fourth day reaches the minimum of the next to the last day of the long series. The average of these days is very much better than that of the last days of the fast series or even of the first days, so that there is no doubt of an improvement in these reactions.

The cancellation test (XXI) begins at about the point of the twenty-seventh day and the time gradually decreases, but at the sixth day has not reached the rapid time of the last fast day; but judging from the slope of the curve, one would expect it to do so shortly, so that one can conclude that the mental functions necessary for this test are in about the same state they were at the end of the fast. There were only 6 mistakes, 4 of them being on the first day.

[1]It was thought that a year's intermission would make the old lists equivalent to new ones and as one would then be sure of having the lists of this series of the same quality with those of the former, the old lists were used on the first day, but 7 of the 20 reactions were the same as those made a year ago, so that new lists were made.

CORRELATIONS.

It would be supposed that there would be very good and very poor days upon which all the curves would show proportionate increases or decreases, or that at least similar tests, such as those of the higher mental processes, would show similar variations. If we compare some of the crests and valleys, however, we arrive at negative results. For instance, on the twenty-second day the association time (XIII) is long and both memory curves (I A and II A) are in a valley, but the cancellation test (XXI) shows improvement, and the reproduction times (XIX) are not long. On the sixteenth day the left hand reaches a maximum in the strength tests (V), but the right hand (VII) shows no such result. Tapping (III) rises on that day, but it is still comparatively low; one memory curve has fallen (II A) and the association time (XIII) has risen. On the fifteenth and seventeenth days the memory curve (II A) is at a maximum and the association time (XIII) is also lower; the cancellation test (XXI) is also low on these days, but the maximum of the memory tests (I A, II A) on the thirty-first day finds the association times (XIII) longer. On the twelfth day the curves for the strength tests (V, VII) have risen for both hands—it is the maximum for the right hand—the time for the cancellation tests (XXI) has shortened and memory (I A) is better, but the tapping record (III) has fallen and both association (XIII) and reproduction times (XIX) are at a peak. The considerable lengthening of the time of the cancellation test (XXI) on the sixth day finds a betterment in most of the other tests, the tapping test (III) indeed, having reached its maximum on that day. The visual acuity curve (XII) rises abruptly to its maximum on the fourteenth day and, although with a few exceptions the curves show a slight betterment, the rise is comparatively insignificant.

It must be concluded, therefore, that with the exception of the last day the daily fluctuations can not be traced to any one cause, such as a general bodily fatigue and depressed mood or vigorous and cheerful mental states, but that either there is a change in the one or more processes essential to the particular test that is showing the exceptional rise or fall or that there has been a momentary wave of fatigue or distraction or spurt, etc. A diary of the fast was kept in which every important incident was noted and it is possible that many of the fluctuations in particular curves or changes in general tendencies of several of the curves could be more or less satisfactorily explained. The following considerations, however, make such explanations of doubtful value. One can not say in advance what the effect of visits or other changes in the general routine may be. Much depends upon the particular circumstances. Now, if the results were better after a certain visit, one could say that the subject was in a pleasant mood after the break in the monotony of the days and that his mind had been stimulated by agreeable conversation. If the results were worse on those days, one

could say with equal weight that the fatigue following the unusual exertion was the cause. Only the most reliable introspection on the part of the subject before and after each test could have given strength to such explanations, and both the lack of time and training on the part of the subject made such a procedure impossible.

It did seem possible, however, to make an exception of the days on which L. took a drive or was allowed on the roof and that if the curves showed an agreement in their fluctuations on these days an unequivocal explanation could be found. The drives were taken on the fourteenth, seventeenth, twentieth, twenty-second, twenty-fourth, twenty-ninth, thirty-first, and thirty-second days; the visits to the roof on the tenth, fifteenth, twenty-first, and thirtieth days. As was stated above, there was no general agreement even on these days. In regard to the individual curves, however, the visual acuity curve seemed to show the influence of the drives. The best result in the visual acuity test was made on the first drive day and the curve always ascends on the drive days, although not always to a peak. It falls, however, on all but one day when a visit was made to the roof; that it rises on the drive days is contrary to what one would expect and is difficult of explanation, since the subject's eyes should, if anything, have been fatigued by the increased light. If there had been a stimulation of the central processes causing a heightened power of discrimination, this ought to have influenced the other curves as well.

GENERAL SUMMARY AND CONCLUSIONS.

The fact that a human being could live for a month or longer without food had already been satisfactorily proved.[1] Merlatti is reported to have fasted for 50 days and Dr. Tanner for 40 days. The fast of Succi[2] is most similar to that of L. in that it was undergone for about the same length of time and under similarly strict scientific control, although never before had quite so many precautions been taken as in the case of L. Succi fasted for 30 days, but took pepton on the twenty-seventh day. L. continued for one day longer, absolutely nothing but distilled water passing his lips during that time. Both men remained in good physical condition throughout and seemed at no time to suffer any unusual discomfort. It was with difficulty that L. was persuaded to discontinue his fast on the thirty-first day. Although Luciani doubted that Succi was mentally normal, general observations and the tests pointed to a sound mind in the case of L. Both men were, naturally, men of great determination and above all of

[1]E. Bardier, in his article "La Faim" (Ch. Richet's Dictionnaire de Physiologie, 1904, 6, p. 3), remarks in regard to voluntary and involuntary fasts: "On pourra se soumettre volontairement à un jeûne prolongé, comme l'expérience en a plusiers fois été tentée, et endurer assez facilement les souffrances de la faim. Le besoin de manger sera d'autant moins douloureux, d'autant plus facile à supporter qu'il suffira d'un signe pour être mis en face d'un succulent repas. Au contraire, la faim sera beaucoup plus pénible, ses manifestations beaucoup plus douloureuses, si l'on se croit—dans un naufrage, dans une expédition—voué à une inanition complète sans espoir de salut." On page 6, in reference to forced fasting, he further says: "La lutte que l'on est obligé de soutenir contre les causes mêmes de cette inanition augmente la sensation de faim."

[2]Das Hungern, by Luigi Luciani. Translated into German by Dr. M. O. Fraenkel. 1890.

implicit faith and confidence in their idea. L. believed fasting to be a panacea for all ills and the very fact that he is of that type of man who can narrow his horizon about an idea and stubbornly resist all invasions gave him the best equipment for the fight against the natural demands of the flesh. Such a type of mind can not be called abnormal, although it is unusual. The feeling of hunger was at all times, even during the first stages of the fast, denied by L. This statement should not be disbelieved, even though frequently there is extreme discomfort, which those who fast tell us only disappears after the second or third day, as in the case of Succi. With L. and perhaps with other fasters this feeling of hunger may have been suppressed from the beginning by auto-suggestion. The fact of the deep-ingrained faith in the fast makes this plausible.[1]

The condition of Succi's higher mental processes was only ascertained by general observation. These observations agree with those made upon L. There was at no time any symptom of hallucination or lack of clearness in the thought processes. Luciani writes:

"Am 13 Hungertage wollte ich seine Ausdauer bez. geistiger Anstrengungen auf die Probe stellen, indem ich ihm schwierige oder unlösliche metaphysische und theosophische Fragen vorlegte und beständig Einwürfe gegen seine Antworten erhob, in der Absicht, seinen Verstand zu ermüden. Ich muss gestehen, nicht bemerkt zu haben, dass sein Geist dabei mehr ermüdete als der jedes andern Sterblichen von gleichem Bildungsgrade und gleicher Begabung, wenn man ihn solchergestalt martert."[2]

L. is a man of a much higher level of intelligence and intellectual training than Succi. At all times during the fast he was very eager to enter into discussions upon abstract subjects such as the value of the Esperanto language, the political conditions in Malta, the possibility of mental telepathy, and theories of spiritism, as well as the value of fasting. It could not be observed that there was any diminution of his argumentative powers or lack of lucidity of expression. When aroused to counter argumentation he showed the same energy in reply at the end as at the beginning of the fast.

Succi's muscular strength as well as his sensory acuity was ascertained in a manner somewhat similar to the method employed for L., and the results will be compared in the following summary and interpretation of results:

(1) In the dynamometer tests made upon Succi it is impossible to tell from the text how many trials were made daily. As the curves for

[1]E. Bardier, in criticizing Bernheim, writes: "Au sens où l'entend Bernheim, les jeûneurs qui se soumettent à l'inanition résistent facilement, tout simplement par le fait d'une auto-suggestion. Discutant en particulier le jeûne de Cetti, il admet que ce dernier--tout en n'étant pas un hysterique--s'est suggestionné. Il demeure convaincu qu'il conservait toute sa force physique, 'cela suffit pour réaliser le phénomène; l'idée fait l'acte; il s'exalte, il s'entraîne, il se nourrit de son idée, il se montre avec complaisance à ses visiteurs, il jouit de son triomphe; l'esprit domine le corps; etc.' . . . Le jeûneur, par sa volonté, arrive à résister à l'habitude de manger; il obéit à sa conscience qui le soumet à l'abstinence, mais certainement sa volonté doit être incapable de provoquer la suppression d'une sensation." La Faim in Ch. Richet's Dictionnaire de Physiologie, 1904, 6, p. 10. See also footnote 3, p. 191 of this publication.

[2]Luciani, Das Hungern. German translation by Dr. M. O. Fraenkel, 1890, pp. 68–69.

the 10 trials and for the initial trial for L. are similar, the 10-trial curve will be considered. It is safe to assume from lack of mention of the fact and from the nature of the curves that Succi was right-handed. It will therefore be necessary to compare the curve of the right hand of Succi with that of the left hand of L.

It will be remembered that the strength of both hands was found to increase after the drop on the second day until the right hand (VII, fig. 26) reached its maximum on the twelfth day and the left hand (V, fig. 25) on the sixteenth day, both curves then dropping steadily from this point, the right, however, less than the left, for the left reached a minimum on the thirty-first day, while the right during the fast never dropped as low as the record of the nineteenth day. There is a very striking similarity between these and Succi's tests.[1] Both of Succi's curves also drop after the first trials and then rise again, his left reaching a maximum on the fourteenth, his right hand on the twentieth day, as compared to the twelfth and sixteenth days of L. Succi's curves then drop also, but the left drops more than the right, which is the reverse of L.'s curves. With Succi both maximums are greater than the first day's records, while with L. this is the case with only the left hand. This agrees, however, with L.'s records for the initial daily trials (IX and X, fig. 27). Further, L. was able to make a spurt at the end of the fast with both hands, this spurt extending through several days. Succi was only able to spurt with one hand and that on the last day, the curve for the other hand remaining stationary.

Luciani attributed the rise of the curve alone to auto-suggestion. It seems quite probable, inasmuch as Succi and possibly L. also believed that their strength would be increased by the fast, that this idea strengthened their determination and that they bettered their results by sheer "will power."[2] There is, however, another possibility which may be assumed without denying the influence of auto-suggestion, namely, that, at least in the case of L., who was unused to such tests, the coordination of the muscles became gradually more perfect, and further, that these muscles, which were being exercised daily, increased for a time in strength as they would have done under normal conditions, but in this case possibly to the detriment of other muscle groups. In both cases, with both hands, fatigue gained the ascendency over practice effect and possibly over auto-suggestion about the middle of the fast, causing the curves to drop. In the case of L.'s unpracticed hand, however, the effect of practice had more room to work and held the curve up longer than in the case of the practiced hand.

(2) The tapping test (III, fig. 24) is also influenced by the condition of the muscular tissue, but there is another factor more essential here

[1]Luciani, Das Hungern, 1890, p. 55.

[2]E. K. Strong, Jr., in his paper entitled "The effect of various types of suggestion upon muscular activity" (Psych. Rev., 1910, p. 278), says: "The auto-suggestion tends most strongly of all the types of suggestion to heighten the maxima."

than strength, and that is the reaction time. As in the strength tests, there is a rise at first, but here it is of much shorter duration, the maximum of 215 taps in 30 seconds being reached on the sixth day. The following considerable drop until the fifteenth day, at a time when the strength tests are showing more efficiency, may possibly be caused by a lessening in the interest for this test.[1] About the middle of the series this interest and increased effort for a good record may have returned, judging from the results, but fatigue had by that time set in and the curve, although rising until the last day, is never quite able to reach the maximum of the sixth day; that is, there was some falling off in the rapidity of reaction, which, judging from the results of the strength test, was due rather to a change in the muscle tissue than to a change in the nervous arc.[2] From what we know of the effect of practice in such tests it is most probable that if it had not been for this increased muscular fatigue the curve would have reached an appreciable maximum at the end of the series. From the fact of the very small difference between the average of the first 10 and last 10 seconds on the sixth day, when the maximum was reached, as compared with the great difference in the almost equally good result of the last day, it is evident that on the first day the good performance of the first 10 seconds practically continues throughout (in both instances the best record was made during the first 10 seconds), while on the last day the effect of practice as shown in the initial performance was counterbalanced toward the end by fatigue.[3] These results seem to cast further doubt upon Luciani's hypothesis of auto-suggestion in the strength test, for surely auto-suggestion should play as great, if not a greater, role in the tapping tests during those days in which according to the strength tests it would have to be assumed at work. The results of the tapping tests are indeed directly opposed to such a theory.

To sum up, it may then be said that though initial lack of interest and later muscular fatigue played a role, both factors being directed toward a decrease in the amount of work, yet central factors toward the end brought the curve back to its initial level and almost to its maximum.

[1]See pp. 194 and 196.

[2]As the tapping tests preceded the strength tests, the objection can not be raised that the hand was being unusually fatigued by these latter tests.

In reference to the tapping test under normal conditions, Wells writes that "The objective fatigue phenomena which we note in the test are in all probability fatigue phenomena in the refractory phase or a lowered efficiency of coördination, equally a product of altered synaptic conditions; the sensations of fatigue, on the other hand, may with equal assurance be ascribed to tissue changes within the muscles that take place as a result of their continued effort." (F. L. Wells. Normal performance in the tapping test before and during practice, with special reference to fatigue phenomena. Am. Journ. Psych., 1908, p. 473.) In the above tests the change in muscular tissue is due to emaciation, a fact that does not play a role in the test to which Wells refers. At no time did L. speak of sensations of fatigue, and judging alone from his facial and bodily expressions there are no data from which to assume that they were greater at the end than at the beginning of the fast. As to the synaptic conditions, there is nothing in the test to point to a change.

[3]Wells writes: "The true practice gain is one mainly in the initial efficiency of performance, as distinguished from the warming-up gain, which shows itself chiefly in continued efficiency of performance." Am. Journ. Psych., 1908, p. 478.

(3) The threshold for tactual-space perception (XI, fig. 28) decreased somewhat as the fast progressed. It was on the average much better during the last half than the first half of the series. Similar tests were made upon Succi upon a number of different parts of the body, but only on 3 days, before the fast, on the fifteenth day, and on the twenty-ninth day. On some parts of the body there was an increase, on other parts a decrease. Luciani believed the difference in the 3 days due to differences in degree of attention. On that part of the body corresponding most closely to the spot used in these tests, *i. e.*, the lower third of the volar side of the forearm, there happened to be a rather large decrease in the threshold, the three thresholds being respectively 16, 11, and 10 mm.[1] Authorities differ as to whether practice lowers the threshold in tests performed under normal conditions. Dresslar,[2] for example, found that practice had a considerable effect. Solomons[3] found that if the subject is not informed of his errors there is no effect of practice. In the above tests the subject was never told of his mistakes and "vexier" trials were introduced at frequent intervals and in no special order, yet there was a lowering of the threshold. This may be and probably is due to several causes. A physiological cause would be a decrease in the fat, thus exposing the nerve endings and making them more sensitive. On the psychological side increased attention, which we find indicated in other of the tests, would lower the threshold for discrimination. Also, as the tests progress the image of the criterion used becomes cleared. From what is known of the process of perception, this is a most important factor in explaining the above effect of practice. The physiological change is the only one which could be attributed unequivocally to the fast. The central change occurs in series under normal conditions.

If, as has often been assumed, the tactual space threshold test is a measure of mental fatigue, then it must be concluded that there is no indication of such fatigue during the fast.

(4) The visual acuity (XII, fig. 28) showed an astonishing betterment. From 17 feet as the distance of clear vision for the particular test card employed, the curve ascended rapidly to 37 feet on the fourteenth day and, although there is a falling off, 36 feet is the record for the last day of the fast.

If it were not for the maximum of 37 feet midway in the series, the improvement would be comparatively a steady one. One explanation that suggests itself is that the possible change in intra-ocular tension caused the eye-ball to change its shape. Unless his glasses were not the proper ones for him, however, a change in the eye should cause more rather than less difficulty as long as he wore his glasses. Further, the suddenness of the rise seems to vitiate such a theory.

[1]Luciani, Das Hungern, 1890, p. 64.
[2]F. B. Dresslar. Studies in the psychology of touch. Am. Journ. Psych., pp. 313–368. 1894.
[3]L. M. Solomons. Discrimination in cutaneous sensations. Psych. Rev., pp. 246–250. 1897.

A satisfactory explanation seems difficult to find. It might be said that the 37-foot record was made by chance. This also seems precluded by the fact of the number of previous steps in which 10 correct answers were given and from the evidence of confidence displayed by the subject.[1]

Succi's eyes were examined with the ophthalmoscope and his acuity measured before the fast and on the fifteenth and twenty-eighth days of the fast, but no change was detected.[2] If L. had happened to be measured on the third, sixteenth, and one of the days toward the end of the series only, the change would have been thought as negligible as in the case of Succi. In all such tests where the daily fluctuation is considerable three tests in a month are not sufficient upon which to base a judgment as to the change in sensory acuity or higher mental processes.

(5) The rote memory for digits (II, fig. 23) showed very little change. There is a slight suggestion of improvement during the first half of the series. Judging from the curve which indicates the point at which the first mistake was made (II B), one can say that there was a gradual improvement in this respect, especially in the first half of the series, which is probably in part due to a betterment in the perception of the spoken word, but especially to an increase in attention, it becoming more sustained as the fast progressed. The rote memory for sense words (I A) showed a greater improvement than did that for digits. Here probably the practice effect consisted in the forming of associations between the words. The most marked improvement of all is in the retention after a longer period of time, *i. e.*, after 55 minutes (I B). This is probably also due, in part at least, to the more frequent forming of associations. Besides, the repetition of the same task through so many days undoubtedly strengthened the determining tendency, *i. e.*, the determination taken at the time of memorizing for the words to appear in consciousness again, it remaining either in consciousness or subconsciousness during the interval. According to L.'s statement, his mind did not revert to the task within the hour. Indeed, the other tests followed each other so rapidly that this would have been a difficult thing to do.

Experiments upon memory under normal conditions also show the effect of practice, as evidenced by an appreciable increase in the memory span which may continue for a period of 2 months.[3]

[1]The subject did not know whether he was right or wrong or how many correct answers constituted a threshold, so that the results could not have been prearranged by him; and if they could have been he would not have allowed such a good record on the fourteenth day. The high threshold on the last day is obviously due to his unusually poor physical condition (when, if at any time, one might be justified in speaking of a lack of effort).

[2]Luciani, Das Hungern, 1890, pp. 66–67.

[3]T. L. Bolton. The growth of memory in school children. Am. Journ. Psych., 1892, pp. 362–380.

G. Müller and F. Schumann. Experimentelle Beiträge zur Untersuchung des Gedächtniss, Zeitschr. f. Psych., 6, 1894, pp. 81–190, 257–339.

W. H. Winch. The transfer of improvement in memory in school-children. British Journ. Psych., 1908, pp. 284-293.

(6) The cancellation test (XXI), which employs to a greater degree the higher functions of perception and attention shows the greatest improvement of any of the tests used. This improvement continues from the sixth to the last day of the fast. The accuracy is so high throughout the series that the slight improvement in the latter part of the tests is of no significance. Experiments have shown that fatigue affects the accuracy, so that again we have evidence against an increase in mental fatigue.[1]

Besides an improvement in the above-named functions, the increase in visual acuity may have been a factor in the results. On the other hand, from the results of the tapping test and strength tests one must conclude that the betterment is in no degree due either to a betterment in reaction time or motor ability.

(7) The free association time (XIII, fig. 29) is on the whole shorter during the latter part of the series. If it were not for a rapid drop in the middle of the curve after a rise similar to that in the tapping test the improvement would be comparatively steady. The minimum of 1.3 seconds is reached on the day before the last day of the fast and should be compared rather with the 1.9 seconds of the third day than with the 2.5 seconds of the first day, when L. was unaccustomed to the manner of reaction. Even when this comparison is made it is seen that the improvement is considerable. A separation of the curve into four curves corresponding to the four categories used made a more minute analysis possible. The curves XIV, XV, XVI, and XVII, figs. 30 to 32, show fewer high averages in the second half of the series, but it is only in the abstract curve and in less degree in the adjective series that there are more low averages in the second half of the curve. In fact, in neither of the other two curves is the lowest average of the first half of the series again equaled. This seems to indicate that the betterment in the general average of the 20 words is principally due to a betterment in the reaction to abstract words. It is to be expected that the most difficult associations would show the greatest practice effect. In the noun and verb curve there is an almost steady rise in the middle of the curve corresponding to the rise in the middle of the main curve. I seems plausible to suppose that there is here, as in the tapping test, a falling off of interest, and that this would manifest itself more readily in the easier tasks, in which the reaction is likely to become more nearly mechanical.

The general improvement is also seen in the decrease in the variations of the reaction times. In all four curves the daily variation is much less in the second half of the series. Parallel with this is the decrease in

[1] B. Bourdon. Observations comparatives sur la reconnaissance, la discrimination et l'association. Rev. Phil., 1895, pp. 153–185. A. Binet. Attention et adaptation, Année Psych., 1900, 6, pp. 248–404. C. Ritter. Ermüdungsmessungen, Zeitschr. f. Psych., 1900, pp. 401–444.

the variations within each day, as is shown by the decided drop in the m. v. curve (XVIII, fig. 33).[1]

Although the improvement in the reproduction time is not so great as in the association time, yet it is noticeable, the average of the second half being lower than that of the first, although the very low time of 0.8 second was made on the second day as well as during the second half of the series.

The quality of the associations was good throughout (II, table 21) and showed no striking change.[2] The reproductions were so nearly perfect from the first that nothing can be said in regard to them to support the results of the memory tests. One might add, however, that neither do they contradict those results.

The controlled reaction noun-verb (XX, fig. 34) shows an increasing lengthening of the time until almost the end of the series. It is quite probable that this was caused by an increasing difficulty in the stimulus words selected, a factor which could not well be avoided. No other reason suggests itself why these reactions should have taken a different course from that of the free association tests.

The present methods of testing mental capacity unfortunately do not permit one to make dogmatic statements as to the results of any such tests. In each one a number of functions are involved, any one of which may have produced the variations which occur. For example, the cancellation test involves, among other things, attention and interest, apperception and discrimination, nervous impulse and motor discharge. But when, as here, a set of tests are employed in which the same functions are more or less active and they all show a similar trend, then a conjecture along general lines seems legitimate. Further, when there is a very decided difference and it is known that a certain function is of prime importance, then one is undoubtedly justified in ascribing the outcome of this test to changes in this function. It is desired to make it plain that no exact measurement is claimed, but merely that it has been possible, by means of a number of selected tests, to sketch an outline picture of the condition of L.'s psycho-physiological organism.

[1] Wells conducted long series of association reactions with normal subjects and for all of them found an improvement in the reaction time. (See Practice effect in free association, Am. Journ. Psych., 1911, 22, pp. 1–13.)

[2] W. Weygandt's results are hardly comparable to those obtained in these tests (Ueber die Beinflussung geistiger Leistungen durch Hunger, Psych. Arbeiten, 4, pp. 45–173). His subjects fasted for periods of only 24 and 48 hours at a time. This intermittent fasting may possibly cause a much more pronounced disturbance to the organism than a prolonged fast. That there was greater exhaustion seems to be indicated by the fact that there was an increase in associations by sound. He also finds that there was an increase in the outer as compared with the inner associations. (It is now admitted that such a classification of reaction words can not be made without introspection.) Weygandt also found memory to be affected. The association time was not altered. Aschaffenburg studied the effect on association reactions of the exhaustion produced by a night's work without food or sleep. (Studien ueber Associationen, II Teil. Die Associationen in der Erschöpfung. Psych. Arbeiten, 2, pp. 1–83). He too found a similar decrease in the quality of the reaction words. "Mit der Zunahme der Erschöpfung wirkt die zugerufene Vorstellung immer weniger durch ihre Inhalt; an dessen Stelle bestimmen der Klang und die Tonfarbe die Reaction."

It will be remembered that the tests range from those involving principally the muscle groups to those depending in a higher degree upon central factors. The test depending most on the muscular reactions, *i. e.*, the strength test, showed a falling off. The tapping test, which also involved the muscles but in which the rapidity of reaction was a more important factor, showed no improvement. As soon as one turns, however, to the sensory discriminations one notices an increased efficiency, which is probably due either to a change in the peripheral organs or central processes, or both. Finally all the tests involving the higher processes of attention, perception, and association show improvement. In a word, there was a loss in muscular strength due probably to loss of tissue, a possible gain in sensory acuity and a decided increase in the efficiency of all the central processes. It would be premature to say that the improvement is the direct result of the prolonged abstinence from food, as similar improvement has been observed in such tests under normal conditions, due entirely to the effect of practice. It can be stated, however, with some degree of certainty, that the complete abstinence from food for 31 days had little effect upon the higher mental functions, which were able to develop through practice very much as they would have done under normal conditions.

This agrees with the observations upon the physiological conditions. It has been found that during a fast the muscle tissues are the first to suffer and the nervous tissues the last. From these results it seems that up to the thirty-first day the nervous tissues have not suffered.

These results also confirm in part the general observations made by those fasting. It is frequently stated by them that they can do better mental work. The results show that at least they can do approximately as well, and it is not at all unlikely that some can do better, for it must be remembered that there is none of that sluggishness of the mental processes directly after eating, when the digestive processes are at their height, and there is also absence of indigestion and the after-effects of alcohol and tobacco. That, on the other hand, as has been often claimed, they are able to do more muscular work and that their power of endurance is greater is in this case at least not true. Probably the contrast of their actual results compared with what they expected would happen to a man without food makes the result seem greater than it is. The claim that the senses are more acute has been verified as to the visual acuity. It is hardly likely that the slight difference in the tactual-space threshold would have been noticed by the faster.[1]

The question remains as to whether prolonged fasting is beneficial or dangerous to the organism. This can only be satisfactorily answered

[1]L. stated that the heightened sensitivity for odors made walking on the streets of Malta during his first fast positively unpleasant. The other senses were examined in the case of Succi and no appreciable change discovered. Luciani, Das Hungern, 1890.

Whipple (Manual of Mental and Physical Tests, Baltimore, 1910, p. 215), in speaking of the effect of practice in the æsthesiometer test, remarks that Dresslar states: "This practice effect is . . . rapidly lost, being reduced very definitely within 8 days and completely lost within a month."

after an exhaustive physiological examination extending over a long period of time subsequent to the fast. The tests made after the lapse of a year permit, however, of some conjecture in this regard concerning those functions at least which have been discussed in this paper.

The strength test shows a great improvement over the former record. L. exerted a pressure considerably greater than at any time during the long series. The record for the tapping test is also above the maximum of the previous record. The association test shows a marked improvement and the reproduction is also better, especially in that it varies less, and the retention of sense words has perhaps also slightly improved. The tactual-space threshold and the rote memory for sense words are about the same as at the end of the fast. Only in the case of the memory for digits and in the cancellation test has the previous maximum not been reached, but both of these results show consistently good results. It may be stated, in short, that after an entire year's intermission the curves continued practically from the point they had previously reached, if not considerably above that point, without showing that loss of practice which might well have been expected. These improved conditions are, however, not necessarily traceable directly to the beneficial effects of the fast. In regard to the association tests L. has undoubtedly become still better acquainted with the English language, and in respect to the strength tests it must be noted that L. has exercised his muscles daily, according to his report. In general he has led a careful life, paying especial attention to his diet. The possible effect of climate and his new surroundings is also to be considered. Finally, and most important, is the possibility that there was actually a greater effect of practice in the first series than appeared in the records, but that it was concealed by certain opposing effects of the fast, so that the results of the later tests may not be quite what might be supposed from a comparison of the records.

It remains, however, an indisputable fact that, according to the tests made, there was no lasting evil effect of the fast, either upon muscular strength or mental activity.

APPENDIX I.—DREAMS.

As has been already stated, L. was asked to recount the dreams he had had during the previous night. From these records those dreams are here given which pertain to food. It will be seen that at one time he ate, at another refused food, but in neither case was there evi dence of anything but a normal emotional reaction. According to the Freudian theory this absence of an intense emotional state (there were no nightmares nor anything else in the records indicative either of mental or bodily distress) means that the will ("wish") to fast was too strong to allow of any serious conflict of ideas. A great part of the dreams are of a sexual nature and are not here given.

April 13. I saw a basket covered with a white piece of cloth, which I imagined full of food. When I tried to uncover it several black rats jumped out of it and frightened me.

I dreamed I was passing down one of our streets in Malta with a paper bag under my arm containing cheese-cakes for my daughter. I found myself in a state of mental excitement and after going a certain distance I found that the lower end of the bag was opened and the cheese cakes were gone. In their stead was a white hand.

April 19. I dreamed I was in a shop and on the counter there was a very big ham, about 10 feet in diameter. The proprietor was riding on the top of it with a knife in one hand. "It is a very good one," he said. I answered, "I do not like it. Do you not know I am fasting?" Then a friar came in and said, "I will take it in his stead, because I like it." He took it and swallowed it.

April 21. I dreamed I had been for a walk in the country. I went to a country tavern and asked for something to eat. The proprietor gave me a beefsteak and some fried red fish. I ate them with relish and asked what I had to pay. He told me $1.50 and asked if that was too much. I said I did not think so. In coming out of the tavern I saw a river full of these red fish and people were trying to catch them. I said, "You are fishing out all the fish and if you continue you will not have any more to eat."

APPENDIX II—COMPLETE SERIES OF ASSOCIATION TESTS.

April 11, 1912:

Stimulus word.	*Reaction word.*	*Reaction time.*
Paper	ink	2.2″
Bright	light	2.0
Yellow	lemon	1.8
Table	knife	1.2
Spoon	broth	2.8
Apple	stem	2.4
Sleep	bed	1.6
Room	door	1.3
Face	eye	2.0
Carpet	red	1.8
Animal	white	2.6
Rain	noise	5.0
Teach	bench	2.0
Doctor	knife	4.0
Book	no. of pages	3.8
Store	glass window	1.6
Horse	tail	2.2
Island	trees	2.2
Journey	ship	2.2
Freedom	banner	2.0
Sweet	sugar	1.2
	Average	2.3

April 12:

Stimulus word.	*Reaction word.*	*Reaction time.*
Round	table	2.0″
Country	green	1.8
Silver	spoon	2.3
Rabbit	white	2.0
Chair	cushion	3.0
Glass	window	2.0
Flower	odor	2.3
Sun	brightness	3.2
Bread	white	2.3
Wood	hard	3.0
Well	water	2.4
Danger	sea	2.0
Tired	bed	2.0
Watch	gold	2.4
Marble	table	1.6
Iron	bar	3.8
Bridge	iron	2.8
Blind	dark	2.4
Pencil	wood	3.0
Candy	sweet	3.4
	Average	2.5

April 13:

Stimulus word.	*Reaction word.*	*Reaction time.*
Timid	rabbit	3.0″
Pulse	hand	9.0
Mystery	religion	5.2
Savage	wolf	2.4
Spirit	angel	2.4
Teeth	to eat	2.6
Bargain	profit	5.0
Blunder	mistake	3.0
Temper	nervous	2.2
Abrupt	cascade	2.0
Harp	sing	2.0
Switch	machine	2.4
Wide	sea	2.2
Tailor	stuff	3.0
Income	money	1.5
Splendor	sun	1.8
(Salve) solve	lip	2.5
Moon	silver	2.2
Frost	white	1.8
License	wine	1.8
	Average	2.9

April 14:

Accept	a reward	2.8″
Air	blue	2.6
Able	sailor	2.0
Abuse	drink	2.6
Address	letter	1.8
Blood	red	1.1
Bad	man	1.4
Age	90	1.2
Agree	wife	1.0
Boot	black	1.8
(Tall) ball	tree	1.6
Balance	weight	1.6
Amuse	theater	1.4
Bottle	ink	1.4
Band	brass	1.4
Climate	mild	0.8
Bite	dog	1.5
Box	wooden	1.6
Contents	book	6.4
Boy	small	1.8
	Average	1.9

April 15:

Catch	bird	1.6″
Brain	human	2.6
Broad	street	1.4
Courage	man	2.2
Cease	speak	2.2
Brick	red	1.6
Broken	glass	1.0
Culture	physical culture	1.6
Compel	servant	3.4
Cable	iron wire	1.4
Central	station	1.6
Crowd	people	1.2
Confess	priest	1.0
Carbon	carbon dioxide	1.8
Common	sense	1.0
Day	night	2.0
Control	engine	1.0
Chain	iron	1.0
Course	study	2.2
Delegate	apostolic	2.0
	Average	1.7

April 16:

Stimulus word.	*Reaction word.*	*Reaction time.*
Defend	country	1.8″
Deck	ship	1.2
Fresh	air	0.8
Faculty	arts	1.0
Deduct	sum	1.4
Dinner	good	1.4
Flavor	odor	2.2
Displease	anyone	3.2
Dog	large	2.0
Good	man	0.6
Fault	his fault	3.0
Egg	white	1.4
Green	tree	1.8
Fright	dog	2.2
Drive	horse	1.2
Fairy	tale	1.4
Hard	stone	0.8
Function	ceremony	3.2
Profess	religion	1.4
Salt	sea	1.4
	Average	1.7

April 17:

Crawl	serpent	2.0″
Clown	buffoon	2.4
Dizzy	headache	1.6
Distance	my country	2.0
Cure	physic	2.6
Corn	grass	1.8
Easy	chair	1.8
Distress	sorrow	2.0
Decorate	church	1.6
Copper	metal	1.4
Even	ground	2.4
Endurance	fasting	1.4
Decline	age	1.0
Cream	sweet	2.0
Firm	strong	3.4
East	west	1.0
Degrade	man	1.8
Corset	woman	1.0
Flat	floor	1.8
End	book	3.0
	Average	1.9

April 18:

Hit	hammer	3.0″
Swallow	food	1.2
Suffer	pain	1.2
Build	house	1.3
Rubber	teeth	1.4
Food	good	1.0
Park	large	1.1
Boat	swim	1.8
Smooth	floor	1.1
Straight	way	1.8
Ugly	man	1.8
Gentle	woman	1.4
Naughty	man	2.0
Power	England	1.6
Strength	athlete	1.9
Charm	woman	3.0
Cost	money	1.0
Kindness	woman	2.2
Break	glass	1.2
Jaw	mouth	1.8
	Average	1.6

April 19:

Stimulus word.	*Reaction word.*	*Reaction time.*
Produce	field	1.4″
Cry	baby	1.0
Freeze	cold	1.6
Follow	soldier	5.8
Smoke	pipe	0.8
Rope	long	2.0
Omelet	eat	1.4
Cap	head	1.0
Burglar	thief	1.6
Delicate	woman	0.8
Thick	paper	2.8
Expensive	money	1.0
Dark	night	1.0
Unfair	unjust	2.0
Purpose	ecope	1.0
Glory	eternal	1.2
Mischief	bad	2.0
Occasion	accident	1.0
Nuisance	wrong	1.6
Overcoat	dress	1.0
	Average	1.6

April 20:

Prefer	office	2.4″
Crush	crowd	2.0
Allow	pension	1.6
Drink	water	1.2
(Solution) salute	salt	2.2
Hip	thigh	1.2
Lightning	thunder	2.0
Parlor	bedroom	2.4
Snake	serpent	1.0
Wicked	man	1.2
Rich	millionaire	1.8
Clean	body	1.2
Bashful	woman	1.0
True	religion	5.2
Exchange	money	1.0
Style	literature	1.0
Power	gun	1.0
Result	good	1.4
Nonsense	foolish	1.6
Seed	plant	1.0
	Average	1.7

April 21:

Pinch	pin	1.4″
Satisfy	appetite	0.8
Nourish	food	1.2
Drift	wind	0.8
Abuse	drink	1.2
Ditch	deep	1.2
Tiger	fierce	1.0
Music	sweet	1.0
Fish	sea	1.4
Death	eternal	(22.4)
Soft	paste	2.4
Ugly	man	1.2
Watchful	policeman	2.6
Indecent	conduct	3.0
Haste	hurry	1.0
Comfort	good	2.0
Adventure	strange	1.2
Practice	long	1.8
Untrue	falsehood	1.6
Merit	high	2.8
	Average	1.6

April 22:

Stimulus word.	*Reaction word.*	*Reaction time.*
Eat	bread	2.0″
Open	door	1.0
Divide	reign	1.8
Fade	flower	1.6
Travel	ship	2.0
Umbrella	rain	0.8
Gift	gold	3.0
Man	long	0.8
Sailor	ship	1.2
School	teacher	1.2
Dense	air	2.0
Short	man	1.4
Weary	travel	1.6
Best	book	5.4
Excuse	pardon	1.6
Insult	bad	3.8
Prudence	woman	1.6
Caution	wise man	2.2
Conceit	ambition	2.2
Captain	ship	1.4
	Average	1.9

April 23:

Collapse	sick	2.4″
Excite	nervous	1.6
Begin	book	1.8
Prosper	progress	2.4
Hat	head	1.2
Sister	brother	1.0
Ham	meat	2.0
Crime	justice	2.8
Tight	shoe	2.0
Solid	stone	1.8
Cold	winter	1.6
Clear	sky	1.4
Hope	fortune	3.6
Dismay	fear	1.6
Offense	insult	1.4
Blunder	mistake	1.0
Future	time	4.0
Insist	persist	2.4
Trap	wolf	2.0
Oblong	square	1.4
	Average	2.0

April 24:

Restore	furniture	1.4″
Impress	printing	1.8
Flirt	woman	1.0
Ask	question	1.2
Receive	letter	0.8
Baker	bread	1.0
Athlete	strength	1.0
Cradle	baby	1.0
Bundle	hay	1.0
Elephant	trunk	1.0
Cheap	money	3.0
Black	dog	0.8
Tender	meat	1.4
Prompt	answer	1.4
Ignorant	man	1.0
Confidence	familiarity	2.0
Jealousy	woman	0.8
Honesty	good	4.2
Unbelief	atheist	2.4
Heroism	warrior	2.0
	Average	1.5

April 25:

Stimulus word.	*Reaction word.*	*Reaction time.*
Join	chain	1.8″
Clasp	hand	1.0
Advance	pretension	2.0
Argue	discussion	2.0
Mountain	large	1.0
House	beautiful	1.4
Neck	strong	1.0
Lamb	quiet	1.2
Hero	brave	1.2
Jealous	woman	1.4
White	snow	2.0
Serious	man	1.0
Vacant	space	1.0
Fertile	land	1.0
Reason	mind	1.6
Protection	government	1.8
Solemnity	festivity	1.0
Impudence	woman	3.8
Convenience	etiquette	3.0
Scratch	nail	1.6
	Average	1.6

April 26:

Forget	memory	1.2″
Dislike	people	1.0
Prepare	lesson	1.0
Admire	virtue	1.8
Protect	children	1.6
Starch	white	1.2
Mutton	meat	1.4
Ostrich	feather	1.0
Roof	house	2.0
Little	boy	1.0
Funny	buffoon	2.2
Gay	sun	1.2
Dead	black	1.2
Slow	worm	1.6
Solemnity	feast	1.6
Annoyance	fly	1.0
Constancy	virtue	3.2
Attention	mind	1.4
Uncertainty	pendulum	(12.6)
	Average	1.4

April 27:

Accuse	judge	1.8″
Appear	star	2.0
Polish	wood	1.2
Repeat	lesson	1.0
Condemn	delinquent	2.4
Car.	motor	1.8
Knee	leg	1.8
Cloud	white	1.2
Fun	joy	1.8
Violent	wind	1.2
Sour	acid	1.0
Dim	sound	1.0
Condition	good	1.0
Deceit	deceive	3.0
Fraud	wrong	3.0
Brutality	animal	2.0
Cup	wine	1.2
Equality	fraternity	3.0
Greasy	pole	1.2
Violet	odor	1.0
	Average	1.7

April 28:

Stimulus word.	*Reaction word.*	*Reaction time.*
Persuade	argument	2.4″
Dig	ditch	1.0
Get	money	1.0
Sting	bee	2.2
Preach	priest	1.0
Spice	pepper	0.8
Star	Venus	1.4
Ice	cold	1.0
Picture	beautiful	1.8
Lip	red	1.4
Easy	chair	1.0
Unclean	dirty	1.4
Red	rose	1.0
Rotten	mud	2.0
Hard	flint	1.0
Proposition	geometry	1.6
Improvement	progress	1.0
Infamy	calumny	2.2
(Competition) competence	commerce	2.4
Attraction	actress	2.0
	Average	1.5

April 29:

Announce	news	1.2″
Stain	ink	1.0
Finish	lesson	1.4
Drag	horse	2.0
Plead	case	2.0
Cork	bottle	2.0
Toy	child	1.2
Key	door	1.2
Ox	horns	2.2
River	water	1.6
Rusty	iron	1.6
Ungracious	bear	2.0
Irksome	science	2.4
Equal	balance	4.0
Late	hour	1.2
Accusation	importation	2.0
Corruption	money	2.0
Poverty	distress	3.2
Imposition	tax	1.0
Adoration	saint	1.4
	Average	1.8

April 30:

Adore	saint	2.2″
Perish	ship	2.2
Propose	marriage	1.4
Uphold	politics	2.8
Descend	stairs	1.2
Slave	misery	2.8
Violin	music	2.0
(Path) pot	country	2.4
Chapel	church	1.4
Trumpet	sound	1.2
Supreme	being	1.2
Elegant	woman	1.6
Impudent	woman	2.0
Blame	offense	2.4
Gain	money	1.0
Idea	noble	1.0
Worship	God	1.0
Elevation	spirit	1.4
Noisy	metronome	2.0
Level	ground	1.0
	Average	1.7

May 1:

Stimulus word.	*Reaction word.*	*Reaction time.*
Escape	prison	2.0″
Admit	argument	2.0
Joke	play	3.0
Improve	mind	1.6
Defy	enemy	1.2
Lamp	fire	2.0
Cabbage	green	1.0
Paste	soft	1.2
Poem	beautiful	1.0
Spear	piercing	2.6
Harsh	sound	1.2
Unripe	fruit	1.0
Unwell	sick	1.0
Vile	fellow	1.0
Admission	employment	3.0
Thankfulness	gratitude	2.0
Dishonor	bad	3.6
Intimacy	friendship	1.0
Revenge	fault	3.4
Least	thing	2.6
	Average	1.9

May 2:

Deny	favor	2.0″
Burn	fire	1.6
Paint	wall	1.8
Betray	faith	1.2
Dress	clothes	1.4
Mouse	black	2.0
Barn	corn	3.0
Song	beautiful	1.4
Spider	feet	2.6
Scarlet	fever	1.6
Beautiful	woman	1.4
Yellow	fever	1.8
Modest	girl	2.0
Wealthy	man	2.0
Justice	right	1.4
Trouble	bad	2.0
Quantity	large	1.6
Reproach	fault	1.2
Energy	force	2.0
Crack	nuts	1.0
	Average	1.8

May 3:

Guide	a traveler	6.4″
Care	a boy	2.3
Denounce	principles	3.8
Drop	stone	1.4
Suspect	fault	2.2
Saddle	horse	1.6
Sleep	bed	2.2
Fog	fruit	1.0
Skin	animal	1.4
Earth	ground	3.2
Rough	weather	1.2
High	mountain	1.2
Idle	servant	1.4
Humble	man	2.0
Active	boy	2.4
Health	good	1.4
Aim	noble	1.8
Fame	vain	2.8
Shame	wrong	2.0
Ability	great	1.2
	Average	2.1

May 4:

Stimulus word.	*Reaction word.*	*Reaction time.*
Fast	long	1.4″
Dream	sleep	2.6
Taste	food	1.2
Cook	food	1.4
Mark	ink	1.0
Sparrow	bird	1.0
Foot	large	1.6
Spider	insect	3.2
Forest	trees	1.0
Stone	heavy	1.0
Purple	color	1.0
Infamous	calumny	1.2
Refined	art	1.2
Ungracious	bear	1.8
Center	circle	1.6
Awkward	gait	1.8
Supremacy	authority	2.0
Constancy	perseverance	1.6
Time	quick	1.2
Gin	bad	1.0
	Average	1.5

May 5:

Invite	guest	1.6″
Pin	clothes	1.4
(Crumble) tremble	bread	1.4
Attack	enemy	1.2
Wood	hard	2.0
Dirt	nasty	3.2
Shoe	tight	1.2
Camp	large	1.8
Cannon	big	2.6
Ashamed	fault	1.4
Unsafe	war	1.6
Raw	fruit	2.0
Smooth	ground	1.2
Fortune	money	1.4
Disdain	angry	2.0
Refinement	art	1.8
Activity	work	1.2
Accident	misfortune	1.6
Scoff	offender	2.4
Noisy	clock	2.0
	Average	1.8

May 6:

Dishonor	sin	2.4″
Remove	furniture	1.6
Injure	sword	2.4
Plunge	water	1.0
Murder	thief	1.4
Garden	flower	1.0
Nut	crack	2.0
Stem	heraldry	2.0
Crab	animal	2.0
Pickle	burning	2.0
Noble	gentleman	1.6
Nice	fellow	1.2
Secure	keys	1.0
Blue	sky	2.0
Swift	sparrow	1.4
Disgrace	fault	2.0
Security	policeman	2.2
Unhappiness	marriage	2.8
Rhyme	poetry	1.0
Disaster	Titanic	1.2
	Average	1.7

May 7:

Stimulus word.	*Reaction word.*	*Reaction time.*
Wash	clothes	1.0″
Elevate	thought	1.4
Deceive	wrong	2.6
Ramble	about	1.6
Decay	reign	1.8
Bible	holy	1.4
Pencil	lead	1.0
Crown	king	1.0
Goat	milk	1.2
Candy	sweet	0.8
Restless	not quiet	2.0
Simple	countryman	1.6
Reckless	man	1.2
Eternal	life	1.2
Prosperity	fortune	1.0
Jealousy	woman	1.2
Concealment	to hide	2.4
Advancement	progress	0.8
Rancid	butter	1.4
Honesty	good	1.0
	Average	1.4

May 8:

Deserve	merit	1.2″
Wish	fortune	2.4
Boast	glory	3.2
Establish	manufactory	1.1
Barber	razor	1.6
Pebble	stone	1.4
Heart	beat	1.2
Machine	work	1.4
Statue	marble	1.2
Certain	thing	2.0
Natural	régime	1.8
Correct	grammar	2.0
Dusty	street	0.8
Enormous	building	1.6
Commandment	God	1.0
Excitement	nervous	0.8
Restoration	food	1.6
Density	mercury	1.8
Infirmity	sickness	1.8
Return	voyage	1.6
	Average	1.6

May 9:

Paper	write	1.2″
Bright	sun	0.6
Yellow	fever	1.4
Table	mahogany	3.2
Spoon	food	1.4
Apple	fruit	0.8
Sleep	night	2.4
Cut	animal	1.8
Face	beautiful	1.2
Carpet	ground	1.4
Animal	fierce	1.6
Rain	weather	1.8
Teach	lesson	1.8
Doctor	medicine	1.0
Book	interesting	1.4
Store	goods	3.0
Horse	animal	1.6
Island	Malta	1.2
Journey	long	1.0
Freedom	liberty	0.8
	Average	1.5

May 10:

Stimulus word.	*Reaction word.*	*Reaction time.*
Roast	meat	1.0″
View	panorama	1.8
Whistle	a whistle	1.4
Alarm	people	2.6
Indulge	drinker	1.4
Frost	white	1.4
Cask	wine	1.0
Curtain	silk	1.4
Nurse	baby	1.2
Ivy	wall	1.4
Thankful	grateful	1.0
Steep	stairs	1.2
Unwholesome	air	1.0
Gentle	woman	1.4
Faithful	servant	1.0
Conflict	nations	1.2
Anger	bad	2.2
Idleness	vice	2.4
Betrayal	traitor	1.8
Denouncement	fault	2.0
	Average	1.5

May 11:

Plunge	water	1.0″
Guess	enigma	2.4
Rescue	wrecked	1.8
Believe	God	1.4
Carve	wood	1.0
Door	house	1.8
Barley	corn	1.0
Eagle	bird	1.0
Chin	face	1.6
Pulse	beating	1.0
Alive	man	1.2
Exquisite	sweet	1.6
Empty	barrel	1.2
Bitter	quassia	1.8
Lazy	fellow	0.8
Modesty	virtue	1.0
Immensity	God	1.6
Preservation	alcohol	1.8
Prudence	virtue	1.2
Indiscretion	vice	1.2
	Average	1.4

May 12:

Find	treasure	2.0″
Praise	merit	2.0
Pump	water	1.0
Try	lesson	1.8
Guard	tower	1.8
Iron	metal	1.8
Stomach	empty	1.8
Salmon	fish	1.0
Bath	water	1.2
Splinter	wood	1.2
Unfit	unable	2.0
Ardent	fire	1.2
North	south	2.2
Handsome	lady	1.2
Price	high	2.2
Appetite	good	1.2
Fable	Æsop	2.0
Definition	grammar	1.8
Queer	sound	2.2
Ingenuity	simplicity	1.4
	Average	1.7

May 13:

Stimulus word.	*Reaction word.*	*Reaction time.*
Distrust	enemy	1.8″
Run	a long way	2.0
Agree	friend	1.2
Needle	thread	1.2
Chocolate	sweet	1.0
Twig	tree	1.2
Napkin	white	1.2
Hill	steep	1.4
Finger	hand	1.0
Pretty	girl	1.2
Contented	happy	1.0
Absent	minded	1.8
Magical	lantern	1.4
Profane	words	1.2
Introduction	to a friend	1.4
Amusement	theater	1.2
Remorse	sin	0.8
Calmness	quietness	1.2
Nod	head	1.0
Calculate	numbers	1.0
	Average	1.3

May 14:

Shock	electricity	1.4″
Sweat	heat	1.8
Melt	snow	1.4
Stun	hit	1.4
Hunt	deer	2.0
Maiden	woman	1.8
Bag	sand	2.0
Belt	leather	1.2
Cake	sweet	1.2
Unhappy	miserable	1.6
Pure	blood	1.8
Disorderly	irregularity	1.6
Unemployed	poor	2.0
Wretched	miserable	2.0
Indulgence	vice	1.6
Agreement	friendship	1.2
Advantage	benefit	1.2
Injury	blow	1.2
Outrage	war	1.6
Rubber	teeth	1.6
	Average	1.6

May 15:

Sin	bad	1.4″
Applaud	merit	0.8
Astonish	marvel	1.6
Rejoice	good news	2.0
Use	tools	1.2
Spool	loom	1.4
Sheep	fur	1.6
Emerald	precious stone	1.8
Wagon	coal	1.6
Cottage	college	1.6
Naughty	boy	1.2
Exacting	demand	2.6
Thirsty	man	1.2
Playful	boy	1.2
Impulsive	dashing	1.8
Faithfulness	dog	1.0
Provocation	insult	1.4
Contentment	happiness	1.0
Religion	faith	1.0
Profanity	bad word	1.0
	Average	1.4

June 2, 1913:

Stimulus word.	*Reaction word.*	*Reaction time.*
Adore	God	1.0″
Perish	ship	1.0
Propose	marriage	1.1
Uphold	opinion	1.8
Descend	mountain	1.2
Slave	poor	2.2
Violin	song	1.6
Brook	river	1.0
Chapel	church	1.0
Trumpet	sound	1.0
Supreme	Being	1.2
Elegant	lady	1.2
Impudent	boy	2.8
Blame	fault	2.1
Gain	money	0.8
Idea	beautiful	1.4
Worship	God	1.6
Comfort	pleasure	3.0
Noisy	room	1.0
Level	ground	1.0
	Average	1.4

June 3:

Cover	hat	1.3″
Hasten	pace	1.0
Curse	son	3.6
Hurt	wound	1.4
Blush	young lady	2.2
Island	Malta	0.8
Copper	metal	1.0
Water	flowing	1.0
Lettuce	vegetable	1.4
Brandy	alcohol	1.0
Unseen	God	1.0
Merry	happy	1.6
Sacred	church	1.4
Excellent	exam	1.6
Adorable	saint	1.4
Life	Eternal	1.2
Opposition	enemy	1.2
Intellect	mind	1.2
Sorrow	grief	1.4
Education	school	1.2
	Average	1.4

June 4:

Caress	baby	1.4″
Reduce	salary	1.0
Reward	behavior	1.8
Talk	English	1.0
Touch	table	1.0
Street	long	1.0
Cane	reed	1.2
Soap	soft	1.4
Cheese	English	2.0
Drum	sound	1.0
Happy	healthy	2.2
Small	boy	1.0
Difficult	lesson	1.2
Painful	wound	1.2
Grief	sorrow	1.0
Thought	good	1.4
Credit	great	1.6
Fear	death	1.4
Mercy	God	1.2
Sinful	man	1.0
	Average	1.3

June 5:

Stimulus word.	*Reaction word.*	*Reaction time.*
Oppose	enemy	1.2″
Enter	house	1.2
Drive	horse	1.0
Lecture	public	2.2
Flag	wave	1.0
Ivory	white	1.0
Bed	sleep	1.2
Fountain	water	1.0
Pie	lemon	1.6
Awake	morning	1.4
Dull	night	1.4
Many	friends	1.8
Green	leaves	1.2
Divine	God	1.0
Terror	enemy	1.2
Spite	hatred	1.4
Advice	council	2.0
Contempt	enemy	1.8
Dispute	question	1.2
Telephone	friend	2.6
	Average	1.4

June 6:

Scold	child	1.0″
Walk	street	1.0
Punish	criminal	2.2
Smell	odor	1.2
Send	letter	1.4
Mill	flour	1.0
Elbow	hand	1.2
Milk	white	1.0
Scissors	cut	1.2
Moon	night	1.2
Quiet	night	1.4

June 6—Continued.

Stimulus word.	*Reaction word.*	*Reaction time.*
Infinite	God	1.0″
Brave	soldier	1.4
Ornamental	church	1.0
Dreadful	fight	1.4
Chance	good	1.4
Quarrel	men	2.0
Conscience	good	1.2
Scandal	bad	1.8
Evil	bad	1.6
	Average	1.3

June 7:

Irritate	nerves	1.0″
Tame	animal	1.0
Feed	animal	1.2
Imagine	vision	1.0
Suffer	pain	1.0
Dinner	good	1.2
Raft	sea	1.2
Chart	fever	1.8
Glove	hand	1.0
Bird	sing	1.2
Afraid	lion	1.0
Blue	sky	0.8
Anxious	desirous	1.2
Long	street	1.0
Audacious	hero	1.2
Expression	vocal	1.2
Mistake	great	1.2
Devotion	church	1.2
Errand	boy	1.0
Expense	great	1.4
	Average	1.14

FECES.

In the days preceding the fasting period, there was more or less regular defecation, but the special interest in the feces in connection with this fasting experiment has to do with the defecation immediately preceding the fast and that on the days following the fast. After the evening meal on April 13, L. had a large defecation, as was noted in the history for that day. There was *no defecation, however, throughout the entire fasting period*, as no feces were passed from the time of the defecation on April 13 until 5^h30^m p. m. on May 15, *i. e.*, about 8 hours after the first food had been taken. It was suggested to the subject that it would be desirable, especially on the first day or two, to empty the lower bowel with a warm-water enema, but he preferred not to do this.

The defecation on May 15 was coincidental with a severe attack of colic occasioned by the taking of an excessive amount of acid fruits, which flooded the stomach and the intestinal tract. The defecation, which was copious, contained a few hard, well-formed lumps of feces about 1 cm. in diameter and with a total length of 6.5 cm. The rest of the material was spongy and soft, running like liquid when turned from the vessel. The feces had a nauseating odor, necessitating frequent access to the outdoor air in transferring and handling the material. Another defecation took place about 8 p. m., a third shortly afterward, and still another during the night. The feces were all of a very soft and liquid consistency, and of a light yellowish-brown color. As the hard material was obviously entirely different in nature from the soft material it was removed, and probably this alone can here be considered as in any way approximating fasting feces. The second and third defecations were tested with litmus paper and found to be strongly acid, probably due in part to the organic acid present in the fruit juices.

The fact that there were no feces throughout the 31 days of this prolonged fast is of special significance, as it is commonly stated that fasting men excrete from 2 to 5 grams of dry fecal material each day. In the earlier experiments at Wesleyan University, no evidence was found of what might be called strictly fasting feces. In the prolonged fasting experiment with L., since the last defecation prior to the fast took place only a half hour after the last meal on April 13, at least a portion of the feces of May 15 might be expected to result from the food on April 13, so that we find it difficult to determine what proportion, if any, of the material defecated should be ascribed to the fasting period. Unfortunately the exigencies of the situation, especially in view of the illness of the subject, made it impracticable to preserve and prepare these feces for a microscopical examination. This is much to be regretted, as some light might have been thrown upon their source. The amount was, however, extremely small, as the total air-dried

material from the hard portion of the first defecation amounted to but 20.8 grams.

The amount of fasting feces reported in observations made by other investigators is somewhat difficult to explain, except by the fact that they are based in large part upon Mueller's observations on Cetti, who fasted 10 days. It should be noted, however, that during the entire fast Cetti smoked cigarettes more or less and unquestionably shreds of tobacco found their way into the alimentary tract. While these shreds of tobacco by no means formed the bulk of the fecal material, they doubtless stimulated peristalsis, which caused a somewhat rapid movement along the alimentary tract of the epithelial débris and residue of the digestive juices. In view of this probable stimulation in the experiment with Cetti it appears fortunate that our subject L. did not use tobacco in any form during his fast.

It is by no means clear whether the weights recorded by Luciani for the feces in Succi's fast are for dry material—as interpreted by Mueller[1]—or whether the material recovered from the enemata was dried down to the consistency of normal feces. Luciani's expression, "un residuo solido di consistenza pastosa,"[2] would seem to imply that the material was by no means anhydrous. With this interpretation, the amount of dry material found in Succi's 30-day fast would be not far from 37.5 grams or a little over 1 gram per day, instead of 5 grams per day, as computed by Mueller.

In the experiment with L. the fecal material which obviously belonged either to the fasting period or to the food period prior to the fast was separated, dried, and analyzed. The results of the analysis are as follows:

Nitrogen	5.26	p. ct.
Fat	21.11	
Fat saponified	25.42	
Calcium oxide	2.859	
Magnesium oxide	1.026	
Total weight of dried material	20.8	grams.

An inspection of these results shows no noticeable difference from the composition of ordinary feces, so that we have no chemical indications of feces which can be specifically ascribed to the fasting period. Consequently the only definite conclusion that can be drawn is that during the 31-day fast there was no positive evidence of the existence of fasting feces.

In this connection, the following report of Dr. Arthur I. Kendall, of the Harvard Medical School (now professor of bacteriology in the Northwestern University Medical School), on the flora of the intestinal tract of our fasting subject, is of special interest.

[1]Mueller, Archiv f. path. Anat. u. Physiol., 1893, **131**, Supp., p. 107.
[2]Luciani, Fisiologia del digiuno; studi sull' uomo, Florence, 1889, p. 37.

OBSERVATIONS UPON THE BACTERIAL INTESTINAL FLORA OF A STARVING MAN.

By Arthur I. Kendall.

The question of the composition of the normal bacterial flora of adult man has never been satisfactorily settled, although the consensus of opinion appears to be that *B. coli* is the form most commonly found. The observations recorded below, while not conclusive, furnish information which tends to show that at least three organisms may persist in the intestinal tract for a month after all food is withheld, and in this sense these bacteria are noteworthy. The history of the case needs no comment here, other than to state that the subject had no food for 30 days prior to the taking of the sample herein reported.

The material for study was obtained from an enema of sterile physiological salt solution, 300 c.c. in all, which was injected into the rectum, retained for approximately 5 minutes, and recovered in almost full volume. The return fluid (collected in a sterile container, with appropriate precautions) was turbid, with but little odor, practically colorless, and, except for a very small amount of cell detritus, free from particulate matter. No fecal material was recovered.

The fluid was plated in plain agar, in a dilution of $\frac{1}{10,000}$, while a portion (undiluted, and diluted $\frac{1}{1000}$) was examined for anaerobes and certain other bacteria. The latter tests were negative.

The total count on agar plates (in duplicate) was 131 and 133 colonies, respectively, giving a total of 1,310,000 and 1,330,000 bacteria per cubic centimeter of washings. Of the 131 colonies, 4 were identical culturally with *B. mesentericus*, 17 were found to be *Micrococcus ovalis* of Escherich, and the remaining 110 were found to be *B. coli*. *B. coli* was also recovered from fermentation tubes inoculated with 1 c.c. of a $\frac{1}{1,000,000}$ dilution of the washings, thus confirming the count by the plate method for this organism.

These results, while not striking, are interesting for two reasons:

(1) Certain bacteria appear to be able to live upon the intestinal secretions, even when all food is withheld for at least a month.

(2) It appears to be impossible to sterilize the intestinal tract by simple starvation. This latter consideration should be of clinical interest, since it is customary in certain diseases to try to "starve out" bacteria from the intestinal tract.

EXCRETION THROUGH THE SKIN.

So great is the total excretion from the body, in the respiration, urine, and feces, that aside from the sensible perspiration, the skin as a path of excretion is rarely considered in any discussion of the loss of body material. But leaving the sensible perspiration entirely out of consideration, the skin plays an important part, for there is cutaneous respiration, including both the absorption of oxygen and the excretion of carbon dioxide; there is a very considerable insensible perspiration, which in its strictest meaning refers to the vaporization of water from the skin surface; and there are the excretions of both nitrogenous material and chlorides through the skin.

Although the excretion of gaseous and solid material through the skin of the fasting man would normally be expected to be at a minimum, it seemed desirable, in order to establish sharp balances of the nitrogen and particularly of the salts, to determine carefully the cutaneous excretion of soluble nitrogenous materials as well as the sodium-chloride excretion. It was not possible to measure the cutaneous respiration of our subject in any of the forms of respiration apparatus used in the fasting experiment, for in the calorimeter the cutaneous respiration is measured with the pulmonary respiration, and with the respiration apparatus no provision is made for the measurement of the cutaneous respiration.

The excretion of the nitrogenous material and chlorides through the skin as the fast progressed was, however, of particular significance, and arrangements were made for determining these. By nitrogenous material is meant not the dead cuticle, but the excretion of water-soluble material, chiefly in the form of urea. In order to determine this accurately, the body of the subject was given a thorough washing before the fast. He was then sponged with distilled water and a freshly extracted and dried cotton union suit was placed upon him. At the end of the week the union suit was removed, the subject was again sponged with distilled water, and another freshly extracted and dried cotton union suit was given him. The union suit which had been removed was then carefully extracted with distilled water and the extract water evaporated after the addition of acid. The water in which the subject had been bathed was also saved and evaporated after the addition of acid. The entire operation was in the skilled hands of Mr. T. M. Carpenter. By this procedure it was expected that the perspiration accumulating during the week would be absorbed by the cotton union suit and the soluble solids, including salts, urea, or other material, would be extracted by the distilled water.

The nitrogen was determined by the Kjeldahl method. The chlorine was determined by titration with silver nitrate and sulphocyanate.

The total amount of nitrogen and chlorine found each week is given in table 22, in which it is seen that the nitrogen ranged from 0.73 gram in the first week to 0.30 gram in the last week, and the chlorine from 0.39 gram and 0.41 gram for the first two weeks to 0.18 gram in the last week.

It will be noted that as much as 0.1 gram per day of nitrogen in water-soluble material may be excreted through the skin during the first week of fasting and that in all probability this method determines the minimum rather than the maximum amount, since unquestionably there is a continual transformation of urea to ammonium carbonate with a loss of ammonia. On the other hand, it is probably true that the secretory activity of the skin decreased somewhat as the fast progressed, as is evidenced by the values for both nitrogen and chlorine. This loss of nitrogen through the skin has special significance in connection with so-called "nitrogen-balance experiments."

TABLE 22.—*Cutaneous excretion of nitrogen and chlorine in experiment with L.*

Date.	Nitrogen.	Chlorine.
1912.	*gm.*	*gm.*
Apr. 13–Apr. 20[1]	0.73	0.39
Apr. 20–Apr. 27	.39	.41
Apr. 27–May 4	.31	.23
May 4–May 11	.30	.18

[1]The subject was bathed on the evening of April 13 and at the end of each week thereafter.

It has previously been shown[1] that during severe muscular work as much as 200 milligrams of nitrogen may be excreted through the skin *per hour*. If, therefore, the excretion of nitrogen in a fasting experiment with minimum activity amounts to 0.1 gram or more per day, it is obvious that nitrogen-balance experiments which do not take into account this loss through the skin will not give accurate results. I am unaware of any determinations of this kind made on a fasting man, although Zuntz and his co-workers on Monte Rosa recorded the loss of nitrogen and chlorine through the skin in their experiments on the high Alps.[2]

The amount of chlorine excreted through the skin of L. was relatively small, being approximately from 50 to 60 milligrams per day in the first 2 weeks of the fast. During the fourth week of the fast only

[1]Benedict, Journ. Biol. Chem., 1906, **1**, p. 263.

[2]Schwenkenbecher and Spitta (Arch. f. exp. Path. u. Pharm., 1907, **56**, p. 284) found about 0.3 gram each of nitrogen and sodium chloride per 24 hours with a healthy person in bed. Taylor (Journ. Biol. Chem., 1911, **9**, p. 21) found with two men at work but no visible perspiration per day 0.028 gram sulphur, 0.003 gram phosphorus, and 0.190 gram nitrogen in one case and the corresponding figures for the other were 0.015, 0.002, and 0.160.

about 25 milligrams per day were thus excreted. While the loss of nitrogenous material from the surface of the skin by decomposition might be considerable throughout the week, it is hardly probable that any large amount of chlorine would be mechanically lost. Thus these values probably represent very nearly the actual cutaneous excretion of chlorine during this period. In this connection it is of interest to note the recent work of Wahlgren,[1] indicating that the skin is one of the principal reservoirs for chlorine in the body. Finally, attention should be called to the discussion of the excretion of water-vapor through the skin,[2] in which the evidence points towards a decreased secretory activity of the skin as the fast continued.

[1]Wahlgren, Archiv f. exp. Path. u. Pharm., 1909, **61**, p. 97.
[2]See page 373.

URINE.

Urine analysis has in the past decade undergone a striking revolution as a result of the development of unique and exceedingly accurate methods by Folin. Formerly clinical examinations of urine included urea determinations, usually by the hypobromite method, and qualitative or roughly quantitative estimations of phosphates, chlorides, etc., but to-day the intelligent clinician deals only with the 24-hour excretion of the various urinary constituents. The introduction of the Kjeldahl method did much to advance our knowledge of the constituents of the urine by giving us information as to the total organic nitrogen, but it remained for Folin to show us the methods for the partition of the nitrogen in the urine and its significance. The ammonia, urea, uric acid, creatinine, and creatine in the urine then began to be of much greater significance than was the total nitrogen; but in all these advances in the development of urine analysis, and particularly in the interpretation of the results, we find stress invariably laid upon the nitrogenous constituents. To such a degree is this true that we are inclined for the most part to think of the urine solely as a path for nitrogen excretion.

Our previous experience with fasting subjects, however, has shown us that in the urine we have not only indices of the protein katabolism, but that with acetone, diacetic acid, and β-oxybutyric acid present, we have indices regarding the defective fat katabolism; furthermore, the inorganic constituents, such as chlorine, phosphorus, sulphur, and the alkaline bases, give us evidence as to the mineral metabolism, the sulphur excretion also having an importance in interpreting the protein katabolism. It was therefore essential to study the urine of our fasting subject not only from the standpoint of protein katabolism, but likewise from every other possible standpoint, so that complete analyses were necessary. In carrying out such a study of the fasting urine, we have depended more largely upon the results of our former study of fasting subjects[1] than in any other part of the research.[2]

GENERAL ROUTINE OF COLLECTION AND SAMPLING.

In order to give us as much information as possible about the previous dietetic habits of this man, particularly for the few weeks prior to

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, pp. 345–419.

[2]After the pages of this book were in page proof, my attention was called to the article from Aoyama's clinic in Tokio, by Watanabe and Sassa, entitled "Die Harnanalyse während des zweiwöchigen Hungerns eines Mannes" (Zeitschr. f. Biol., 1914, **64**, p. 373), issued from Munich on August 27, 1914, but not received here until late in November. It is thus impossible to make any comments upon this interesting paper. The authors studied body-weight, measurements of the body, body-temperature, pulse, respiration, and the blood, but laid special emphasis upon extensive urine analyses. Their findings are, for the most part, in full conformity with those recorded here.

the fasting experiment, L. was requested to measure and sample the urine each day from the first of April until he reached the Nutrition Laboratory on April 10, preserving the samples with chloroform. This he did most carefully, his training as a pharmacist assisting him materially in carrying out the routine accurately. When it is considered that he was traveling rapidly and while on the steamer was obliged to make all his observations and measurements in the narrow confines of a stateroom having three other occupants, it will be seen that it is much to his credit that the records were so carefully kept. Although it was impossible to keep an accurate record of the amount of food eaten, and particularly the kind and amount of the various proteins, a study of these urine samples should give some information as to the normal consumption of protein by this individual.

From the time of his arrival at the Nutrition Laboratory, the collection, measurement, and sampling of the urine were made by members of the laboratory staff. Particular attention was given to the urine excreted during the fasting period, as it was especially important to study the entire output of the body at this time.

When the preliminary arrangements were made for the analyses and their assignment to the various members of the laboratory staff and its co-workers, it soon became apparent that the number of determinations necessary would require a greater volume of urine than would ordinarily be passed by a fasting man. It was therefore arranged, in accordance with a suggestion made by Dr. Cathcart, to provide the subject with a liberal and constant supply of drinking-water. Furthermore, the smallest volume of sample which would give accurate determinations was carefully considered in order to obtain the greatest number of results with the available material. Had it not been for the recent development of the new Folin methods, it is probable that much valuable data would have been lost. For example, while formerly 300 c.c. or even more were required for the determination of the uric acid, with the new Folin method 5 c.c. would suffice. Many of the determinations of the ammonia as carried out by the new method were also made with a relatively small amount of urine.

Before the subject came under observation the time of urinating was more or less irregular. During the three food days preceding the fast, the subject urinated at irregular times, although ending each day at approximately 8 a. m. During the fasting period, he was required to empty the bladder immediately after coming out of the bed calorimeter in the morning, this being usually not far from 8 o'clock. He again emptied the bladder shortly before entering the bed calorimeter at night. We were thus able to divide the urine into two periods, each approximately 12 hours in length. Use was made of this routine in the latter part of the fast to study the apportionment of the nitrogen and ammonia excretion between the day and night periods.

The urine was collected at the laboratory by having the subject urinate into a previously dried and weighed bottle; the bottle and contents were then carefully weighed and the urine measured in a graduate and the volume recorded. Shortly after the experiment began, it was considered advisable, in accordance with a suggestion made by Dr. Folin, to add sufficient distilled water to bring the urine to a definite volume each day. Under these circumstances a normal excretion of urine of 600 to 700 c.c. would be weighed and its specific gravity determined; it would then be immediately diluted to 1,000 c.c. and division made for the various analyses. This procedure was very satisfactory and minimized the calculations.

COMPOSITION OF THE URINE PRIOR TO THE FASTING EXPERIMENT.

As a general indication of the character of the subject's urine prior to the fasting experiment, we have fragmentary data regarding the urine passed on the 10 days before he arrived at the laboratory and for the 3 food days in Boston before the fasting period began. The volume and nitrogen content of this urine are given in table 23, the nitrogen being determined by the Kjeldahl method. In addition to the tabulated data, the ammonia-nitrogen was determined for the last 3 days by the old Folin method, the amounts found being 0.67, 0.65, and 0.59 gram respectively. On the last 2 days the heat of combustion was 129 and 104 calories respectively; the total carbon in the urine for the same days was 11.41 and 9.08 grams respectively. The acidity was determined on but one day (April 11–12), this, expressed as cubic centimeters of N/10 NaOH solution, being 409 c.c. These data will be used in subsequent discussions and are here recorded to avoid confusion with the regular examinations of urine in connection with the fasting experiment.

TABLE 23.—*Nitrogen excreted in urine previous to the fast.*

Date.	Volume of urine.	Nitrogen in urine.
1912.	*c.c.*	*grams.*
Apr. 1–2....	1,095	12.07
2–3....	975	10.90
3–4....	1,208	16.03
4–5....	608	8.83
5–6....	581	11.90
6–7....	818	10.45
7–8....	795	11.30
8–9....	1,215	13.36
9–10...	1,151	12.25
10–11...	1,485	17.02
11–12...	1,521	15.92
12–13...	1,528	14.48
13–14...	1,441	11.54

PHYSICAL CHARACTERISTICS OF THE FASTING URINE.

In considering a subject as complex as is the urinary excretion, it is advantageous to note first the physical characteristics and then the chemical composition. The influence of various physical agencies, particularly the relation between the amount of water drunk and the volume of urine, may not be without influence upon the chemical composition, for under certain conditions there may well be a washing

out of the end-products of protein katabolism by the excess water. Furthermore, the specific gravity (when accurately determined) and also the total solid matter have an interest second only to the chemical constituents of the urine. Accordingly in table 24 a record is given of the water consumed, the volume of urine, the amount of urine in grams, the water in the urine, the ratio of water in the urine to the water consumed, the specific gravity, the total solids, either computed or determined, and the ratio of the total solids to the specific gravity.

TABLE 24.—*Relations between water consumed, water in urine, specific gravity, and total solid matter in experiment with L.*

Date.	Day of fast.	Water consumed. A	Volume of urine. B	Weight of urine. C	Water in urine.[1] D	Ratio of water in urine to water consumed (D÷A). E	Specific gravity. F	Total solids in urine. G	Ratio of total solids to specific gravity. H
1912		*gm.*	*c.c.*	*gm.*	*gm.*			*gm.*	
Apr. 14–15	1st	720	660	673.7	630.2	0.875	1.0206	[2]43.51	...
15–16	2d	750	468	482.0	436.6	.582	1.0303	[2]45.38	...
16–17	3d	750	565	581.2	530.6	.707	1.028	[2]50.62	...
17–18	4th	750	713	730.5	674.4	.899	1.0246	[2]56.13	...
18–19	5th	750	667	682.6	633.5	.845	1.023	[2]49.09	...
19–20	6th	750	610	623.9	577.8	.770	1.0236	[2]46.07	...
20–21	7th	750	524	536.5	495.9	.661	1.0242	[2]40.58	...
21–22	8th	750	587	601.0	556.9	.743	1.0235	[2]44.14	...
22–23	9th	750	607	622.1	575.3	.767	1.0241	[2]46.81	...
23–24	10th	750	565	577.8	535.3	.714	1.0235	[2]42.49	...
24–25	11th	900	564	577.2	535.1	.595	1.0233	[2]42.05	...
25–26	12th	900	517	529.1	489.9	.544	1.0237	[2]39.21	...
26–27	13th	900	561	574.3	532.3	.591	1.0234	[2]42.01	...
27–28	14th	900	647	659.9	619.3	.688	1.0196	[2]40.58	...
28–29	15th	900	758	768.3	735.8	.818	1.0134	[2]32.50	...
29–30	16th	900	889	902.3	861.2	.957	1.0154	41.12	3.0
Apr. 30–May 1	17th	900	848	860.9	821.4	.913	1.0153	39.51	3.0
May 1– 2	18th	900	657	668.8	633.3	.704	1.0177	35.47	3.1
2– 3	19th	900	728	739.6	705.0	.783	1.0153	34.59	3.1
3– 4	20th	900	699	708.7	678.6	.754	1.0143	30.06	3.0
4– 5	21st	900	708	717.2	685.3	.761	1.013	31.88	3.5
5– 6	22d	900	785	794.6	763.4	.848	1.0127	31.18	3.1
6– 7	23d	900	556	565.8	536.5	.596	1.0176	29.30	3.0
7– 8	24th	900	750	759.5	727.5	.808	1.013	32.01	3.3
8– 9	25th	900	713	722.1	691.8	.769	1.0135	30.32	3.1
9–10	26th	900	728	737.1	706.1	.785	1.0129	31.04	3.3
10–11	27th	900	653	662.7	631.2	.701	1.0147	31.52	3.3
11–12	28th	900	655	663.4	634.3	.705	1.0134	29.06	3.3
12–13	29th	900	697	705.8	676.2	.751	1.0129	29.64	3.3
13–14	30th	900	771	780.3	750.7	.834	1.0119	29.58	3.2
14–15	31st	900	566	574.5	547.4	.608	1.0150	27.07	3.2

[1]The amounts of water in urine from Apr. 14–15 to Apr. 28–29 have been obtained by means of computed amounts of total solids.

[2]Calculated by means of the average ratio (3.2) of total solids to specific gravity, determined in the last 16 days of the fast. For the formula used in the computation, see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, page 354.

VOLUME OF URINE.

In the publication giving the results of the earlier fasting research, it was clearly brought out that no one factor affects the volume of urine as does the volume of the water ingested, particularly when the volume of drinking-water is over 1,000 c.c. In the experiment with L., the water consumed was always under 1 liter and hence the influence of the amount of the drinking-water on the volume of the urine was not so obvious.

The volume of urine varied from 468 c.c. on April 15–16 to 889 c.c. on April 29–30. The average volume was 659 c.c. On April 24–25, the volume of the water taken was changed from 750 c.c. to 900 c.c., and it was expected that this change would materially affect the volume of the urine. An inspection of the data shows, however, that it produced no marked effect upon the water excreted in the urine, at least during the first 3 days. Thus, on the 9 days from the second to the tenth days of the fast, inclusive, when the subject drank 750 c.c. of water daily, the average volume of urine was 590 c.c. per day and on the 3 days from the eleventh to the thirteenth days of the fast, inclusive, when the daily amount had been increased to 900 c.c., the average volume of urine per day was 547 c.c. Subsequently there was a distinct tendency for the urine volume to increase and on the next 10 days the average volume was 728 c.c., an increase of 138 c.c. over the period when 750 c.c. of water was taken, closely approximating the increase in the amount of drinking-water. It is to be noted, however, that at this stage of the fast, 900 c.c. of drinking-water was proportionately large for this man's needs, since he had decreased materially in weight. In the earlier fasting experiments, when several liters of water were taken daily, the amount of water drunk unquestionably influenced the amount of water in the urine excreted, but with the comparatively small amount taken by the subject L., the effect was evidently at a minimum, and the absence of any flushing-out of the end-products of protein katabolism simplifies the subsequent discussion.

In comparing the water drunk with the volume of urine, the discussion may be based more advantageously upon the water in the urine. A determination of the solids in the urine was made only on the last 16 days of the fast, but amounts for the earlier days of the fast have been computed and these are sufficiently accurate to use in this connection for obtaining the amount of water in the urine.

From the values given in column E of table 24, showing the relationship between the water in the urine and the water consumed, it is seen that in the first days of fasting, when the amount of water taken by the subject was only 750 c.c., about 74 per cent of the water consumed appeared in the urine. When the amount of drinking-water was increased to 900 c.c., there were marked disturbances in the ratio for the next 7 days. The widest variations in the entire series appeared in

these 7 days, namely, from 54 per cent on April 25–26 to as high as 96 per cent on April 29–30. On the other hand, from May 1–2 to the end of the fast, the ratio remained very constant, with but minor variations above or below the average figure for the whole series of 0.744, essentially that obtaining on the first 10 days of the fast. The disturbance in the ratio was found, therefore, only during the 7 days immediately following the change in the amount of water consumed from 750 c.c. to 900 c.c.

This surprising constancy in the ratio between the water of urine and the water consumed, aside from the 7 days mentioned, is difficult to explain, particularly since at least two factors might have been expected to disturb this relationship. During the first 10 days of the fast, there was a considerable loss of preformed water from the body,[1] ranging from 769 grams to 183 grams. This loss of water might be expected to increase the volume of urine during these days. Indeed, if the volume of urine were not increased, in the absence of other evidence, this might be taken as an argument against such an excretion of preformed water.

Another point which should be taken into consideration in this connection is that one would expect that with the greatly diminished body substance, the amount of drinking-water consumed might exceed the physiological need and hence would disturb the relationship between the volume of urine and the volume of water consumed. On the other hand, it is well known that during fasting there is a tendency for all the tissues to become water-rich, this retention of water possibly compensating for the decrease in the physiological need following the decrease in the size of the organism.

That the relationship between the water of urine and the water consumed is reasonably constant, even when the quantity of water is but 1 liter or less, is likewise substantiated by calculations from data published regarding Cathcart's experiment with Beauté, in which the volume of drinking-water was also constant, *i. e.*, 1,000 c.c. per day. By using the data for the volume of urine, the specific gravity, and the factor 3.2 (see page 244), we have computed the total solids and also the water in the urine for the sixth, seventh, eighth, tenth, eleventh, twelfth, and fourteenth days of Beauté's fast. The ratio of water in the urine to the water consumed was for the several days as follows: 0.813; 0.649; 0.630; 0.940; 0.612; 0.576; 0.662. The average value was 0.697, which is not materially different from 0.750, the average obtained for the values for L. when the 7 days referred to have been omitted. The high value of 0.940 found on the tenth day with Cathcart's subject exceeds any found with our subject L.

In general, then, the volume of water in the urine is approximately 75 per cent of the amount of drinking-water taken, even when but

[1]See discussion of preformed water loss on page 408.

1 liter or less is taken, provided the intake of water is constant. It is obvious, however, that this would hold true only when the factors influencing the loss of water, such as environmental temperature and exercise, also remain constant.

The evidence is clear, therefore, that even with the small amounts of water taken in this fast, there was a reasonably constant relationship between the water consumed and the water in the urine, the absolute fluctuations in the volume of urine noted being so small that there could have been no disproportionate washing out from the tissues of the crystalline end-products of protein katabolism. There is, to be sure, a distinct increase in the average volume of the urine after the twelfth day, but in this experiment we deal with an average increase of approximately 100 c.c., and hence these absolute variations in volume are not to be compared with the very large variations noted in the earlier fasts at Wesleyan University, when the amount of drinking-water varied within wide limits.

SPECIFIC GRAVITY.

The specific gravity of the urine was carefully determined by Miss Alice Johnson, at a constant temperature of 20°C., on a Westphal balance. The position of the scale when the weight was suspended in distilled water was accurately checked, the temperature of the surrounding liquid being invariably artificially maintained at 20° C. Thus the specific gravity of the urine for each day of the fast was readily obtained to the fifth significant figure.

These values, which are given in table 24, ranged from 1.0303 on April 15–16 to 1.0119 on May 13–14, and are therefore well within normal limits. As the fast progressed, there was a distinct tendency for the specific gravity to decrease, although for the first 10 or 12 days it was approximately constant at about 1.024, falling thereafter somewhat sharply and remaining at about 1.015 for the remainder of the fast. This approximation to constancy may be in part accounted for by the approximately constant volumes of urine passed. In the short fasting experiments at Wesleyan University, the specific gravity ranged between 1.0338 and 1.0032, but the lowest specific gravity was accompanied by a very large volume of urine and the high specific gravity by a very small volume of urine.

It is obvious that the nature of the solids dissolved in the urine has a noticeable influence upon the specific gravity. For instance, a solution containing 100 grams of sodium chloride in 1 liter has a density at 15° C. of 1.073, while a solution of urea 1 to 10 has a density of but 1.028; consequently a large amount of sodium chloride in the urine would have considerable effect upon the specific gravity. From other fasting studies it is known that a large amount of sodium chloride is excreted in the first days of fasting, which would thus increase the

specific gravity. After the first few days, the excretion would be in large part of an organic nature, accompanied by the usual salts other than sodium chloride; hence we should normally expect to find the specific gravity somewhat lower in the latter part of the fast.

So close is the relationship between the total solids and the specific gravity that a formula has been in use for many years for computing the total solids by means of this index. Thus, the approximate weight in grams of total solids in 1 liter of normal urine may be calculated by multiplying the last two figures of the specific gravity (as ordinarily expressed in 3 decimal places) by the factor 2.33. The values for the specific gravity were so used for computing the total solids in the urine for a part of the fasting period, substituting 3.2 as the factor.

TOTAL SOLIDS.

In the pressure upon the laboratory staff necessary for carrying out the many details of this elaborate research, the determination of the total solids in the urine was unfortunately overlooked until the latter part of the fast. The data secured in previous researches as to the total solids for the first days of fasting are, however, fairly complete, and we are thus able to supplement these by the important data which were obtained in the last part of this fasting experiment. The procedure followed in determining the total solids was primarily developed for the determination of carbon in urine, and the description of the method applies likewise to the method used for securing the carbon excretion. Three samples of each specimen of urine were prepared in the following manner:

A small soft-metal bottle-cap was first weighed and in this were placed 50 milligrams of pure salicylic acid. With a carefully calibrated pipette, 20 c.c. of urine were next added. The bottle-caps containing the acid and the urine were then placed on the laboratory table in such a position that a current of air from an electric fan would blow over them. This drying was continued over night, usually for a period of about 24 hours. The samples were next dried for 24 hours in a high vacuum in a desiccator. Subsequently the lead capsules with their dried contents were quickly weighed, the 50 milligrams of salicylic acid being subtracted from the final weight of dry matter, thus giving the weight of the total solids in 20 c.c. of urine.

In determining the carbon and the heat of combustion by this method, it is unnecessary to dry the substance in the capsules completely in a high vacuum, but at the end of the 24-hour drying in the current of air, the thick pasty material may at once be transferred to the small capsules used in the combustion bomb. It is thus seen that had we only delayed the weighing of the soft-metal bottle-caps for 24 hours, it would also have been possible for us to determine the total solids in the urine for the first part of the fast.

When the total amount of dry matter was determined, the contents were afterwards carefully transferred from the metal bottle-cap to the nickel capsule by means of a swab of ignited asbestos, the last traces of solid material adhering to the bottle-cap being removed by a bit of asbestos wool moistened with water. Finally, the material was dried in an air-current to a pasty consistency and then placed in a high vacuum until dry enough to burn.

This method has been previously described[1] and need only be referred to here. The 3 samples always gave perfectly agreeing results, indicating that the drying was essentially complete, and testifying to the skilful technique of Mr. Arthur W. Cornell, who carried out the determinations of the total solids, carbon, and heat of combustion. The results of the determinations of the total solids for the last 16 days of the fast are given in table 24, and range from 41.12 grams on April 29–30 to 27.07 grams on the last day of the fast. From these absolute determinations of the total solids, together with the volumes of urine and the specific gravity, it was possible to compute a factor indicating the ratio between the total solids and the specific gravity. This factor, although higher than the value for normal individuals (2.33), remained very constant in these later days of the fast, ranging from 3.0 to 3.5, with an average of 3.2. The value 3.2, which represents the average ratio between the total solids and the specific gravity in the last part of the fast, agrees very closely with those found in three of the fasting experiments with the subject S. A. B. in the Middletown research,[2] namely, experiments Nos. 71, 73, and 75, the ratios being 3.0, 3.4, and 3.3 respectively. In experiment No. 77 with the same subject, much larger amounts of sodium chloride were excreted, and this doubtless was the cause, at least in part, for the lower ratio of 2.5 for this 4-day fasting experiment. In the later days of the fasting experiment with our subject L. there was undoubtedly a minimum sodium-chloride excretion, and the constancy in the ratio between the total solids and the specific gravity points towards an approximately constant relationship between the organic and inorganic solids of the urine. Unfortunately, we are unable to apportion the total solids between the mineral and organic constituents, since it was impossible to determine the ash content of the fasting urine, owing to the deficiency in material. It can only be pointed out here, therefore, that while the factor 3.2 is considerably larger than that accepted for normal people, namely, 2.33, it is probably explained in part by the fact that there were products of defective fat katabolism in the urine.

This average ratio, *i. e.*, 3.2, was used for computing the total solids for the first 15 days of the fast. The results of these computations are also given in table 24. In comparing the values we find that the largest

[1]Higgins and Benedict, Am. Journ. Physiol., 1911, **28**, p. 291.
[2]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 355.

amount was 56.13 grams on April 17–18. It is probable that, owing to the increased sodium-chloride excretion in the first days of fasting, the values are somewhat too high and that the factor used should have been less than 3.2.

DAY AND NIGHT URINES.

While with a fast as prolonged as this the main interest lies in a comparison of the urinary excretion from day to day and there is but little interest in a subdivision of the day into 12-hour periods, yet we have certain fragmentary data regarding the diurnal excretion of urine which are of sufficient importance to record here. Usually the bladder was emptied at 8 a. m. and at 8 p. m., the 24-hour day being thus divided into two periods, *i. e.*, from 8 a. m. to 8 p. m. and from 8 p. m. to 8 a. m. While this subdivision was not made exactly each day, nevertheless the variations were generally well within one-half hour. On one day

TABLE 25.—*Periodic distribution of volume and nitrogen of urine in experiment with L.*

Date.	Day of fast.	Day period.					Night period.				
		Duration.		Vol.	Nitrogen.		Duration.		Vol.	Nitrogen.	
					Amt.	Proportion of total for 24 hours.				Amt.	Proportion of total for 24 hours.
1912.		*a.m.*	*p.m.*	*c.c.*	*gm.*	*p. ct.*	*p.m.*	*a.m.*	*c.c.*	*gm.*	*p. ct.*
Apr. 18–19....	5th.	8h05m	to 7h 27m	307	....	....	7h 27m	to 7h 57m	360	....	....
19–20....	6th.	7 57	8 06	312	....	....	8 06	8 05	298	....	....
20–21....	7th.	8 05	8 02	256	....	....	8 02	8 04	268	....	....
21–22....	8th.	8 04	8 05	298	....	....	8 05	7 59	289	....	....
22–23....	9th.	7 59	8 05	315	....	....	8 05	8 05	292	....	....
23–24....	10th.	8 05	8 03	305	....	....	8 03	7 57	260	....	....
24–25....	11th.	7 57	8 08	284	....	....	8 08	8 04	280	....	....
25–26....	12th.	8 04	8 05	267	....	....	8 05	7 55	250	....	....
26–27....	13th.	7 55	7 22	288	....	....	7 22	8 14	273	....	....
27–28....	14th.	8 14	7 25	252	....	....	7 25	8 07	395	....	....
28–29....	15th.	8 07	7 00	263	....	....	7 00	7 55	495	....	....
29–30....	16th.	7 55	6 55	407	....	....	6 55	7 54	482	....	....
Apr. 30–May 1	17th.	7 54	6 53	328	....	....	6 53	8 06	520	....	....
May 1– 2....	18th.	8 06	6 48	284	....	....	6 48	8 00	373	....	....
2– 3....	19th.	8 00	6 45	250	....	....	6 45	8 07	478	....	....
3– 4....	20th	8 07	6 45	251	....	....	6 45	8 01	448	....	....
4– 5....	21st .	8 01	8 02	[1]300	3.71	46.8	8 02	8 10	[1]418	4.22	53.2
5– 6....	22d..	8 10	8 02	335	....	....	8 02	7 57	450	....	....
6– 7....	23d..	7 57	8 11	266	....	....	8 11	8 00	290	....	....
7– 8....	24th.	8 00	8 00	[1]316	3.94	47.8	8 00	7 55	[1]443	4.30	52.2
8– 9....	25th.	7 55	8 07	323	3.84	48.5	8 07	8 05	390	4.07	51.5
9–10....	26th.	8 05	8 12	282	3.96	49.5	8 12	8 10	446	4.04	50.5
11–12....	28th.	8 08	8 08	242	3.34	44.8	8 08	7 39	413	4.12	55.2
12–13....	29th.	7 39	8 05	300	3.82	50.0	8 05	7 41	396	3.82	50.0
13–14....	30th.	7 41	8 00	311	3.74	49.2	8 00	7 44	460	3.86	50.8
14–15....	31st .	7 44	8 09	266	3.30	48.3	8 09	8 02	300	3.53	51.7

[1]Grams.

(May 10–11) the day period was 14 hours and 5 minutes and the night period only 9 hours and 55 minutes, a discrepancy which resulted in the omission of the day from the record of the periodic distribution of the urine. Beginning with April 18–19, the volumes of the day and night urines were separately recorded. Furthermore, toward the end of the fast, periodic determinations of the nitrogen for the day and night were made. The data thus obtained are given in table 25. Without laying emphasis at this time on the absolute values of total nitrogen excreted—a discussion which belongs later in this report—we may properly consider the data in this table as indicating the division of the urinary excretion between night and day when no food was taken.

The volume of urine during the day ranged from a minimum of 242 c.c. on May 11–12 to a maximum of 407 c.c. on April 29–30. The average volume for the day urine was 293 c.c. The average volume for the night urine was 376 c.c., an increase of 83 c.c. On several occasions there were large differences between the day and night urines, which are not easily explained. Thus, on April 28–29 there were but 263 c.c. in the daytime and 495 c.c. during the night. Although the day period was but 11 hours and the night period 13 hours, this difference in volume is very large. While in general the volumes for the day and the night were not far apart, the average difference, as we have seen, being but 83 c.c., it is indeed surprising that a larger volume was not excreted during the day, for the subject drank his entire allotment of 900 c.c. of water before 8 p. m., taking it in fairly regular portions throughout the day. Usually but a small amount was left after 6 p. m. The drinking of water was thus distributed to obviate the necessity for urinating inside the calorimeter chamber during the night; and indeed, throughout the fast, the subject retained the urine in the bladder the entire night period.

On the days for which we have the data for both the volume and the nitrogen of the urine, we find that on an average 42 per cent of the total volume of urine and 48.1 per cent of the total nitrogen were excreted during the daytime.[1] If the volume of urine had had a material effect upon the total nitrogen, one would expect that a somewhat greater proportion of nitrogen would have been excreted during the night than was actually found, and it is reasonable to suppose that, with the relatively small total volume of urine here involved there could have been but little washing out of the nitrogenous products as a result of the differences in volume. But in view of the well-known fact that large quantities of water assist in washing out nitrogenous material, no other explanation than the increase in the volume of urine seems possible for this small but positive increase in the nitrogen output during the night.

[1]Obviously slight corrections for variations in the relative length of the day and night periods should be made, but an inspection of the table shows that the percentage figures would not be materially altered.

CHEMICAL CONSTITUENTS OF FASTING URINE.

In modern urinary analysis, as carried out in connection with a metabolism experiment, we have several distinct classifications or subdivisions: First, the total nitrogen and the partition of nitrogen in accordance with the analytical scheme of Folin; second, the acid radicles, which would include the chlorine, phosphorus, sulphur, total acidity, and β-oxybutyric acid; third, the bases—calcium, magnesium, potassium, and sodium oxides —whose excretion might perhaps be discussed in connection with the ammonia, itself a base; and finally, attention should be given to the determination of the reducing power, total carbon, and the heat of combustion of urine.

With these various determinations, several ratios can be intelligently discussed, of which the most important may be the ratio of nitrogen to sulphur, nitrogen to phosphorus, carbon and energy to nitrogen, and the heat of combustion to carbon. The presentation of the data secured in our fasting experiment with L. will follow essentially the analytical scheme thus outlined.

TOTAL NITROGEN.

From the early days of the Liebig titration method for determining total nitrogen down through the various modifications to the present-day development of the Kjeldahl technique, one of the first and most important determinations of the constituents of the urine in metabolism experiments has been that of the total nitrogen, the importance increasing in proportion as the technique has been developed. After the accuracy of the Kjeldahl method had been demonstrated and an exact method was thus available, we were informed by Folin, as a result of his beautiful systematic analyses of the urine in which the partition of the nitrogen has been made, that the value of the total nitrogen in the urine did not have the importance which had formerly been attributed to it. For instance, the determination of the carbon-dioxide excretion in a metabolism experiment has great value in itself, but the apportionment of this carbon dioxide to fat, carbohydrate, and protein katabolism has a much greater value; similarly, although the determination of the total nitrogen in the urine is not without value, yet the apportionment of the nitrogen among the various constituents of the urine is much more illuminating and scientifically intelligible than the amount of the total nitrogen. The determinations of the total nitrogen in the fasting urine were therefore made primarily as a preliminary to considering the partition of the nitrogen.

Comparison of Total Nitrogen Excretion of L. with that of Other Fasting Subjects.

While the total nitrogen has been determined in the greater number of prolonged fasting experiments, in relatively few of these studies has the determination been made by the modern Kjeldahl method, the

results in many experiments having been recorded in terms of "urea." Nevertheless, the nitrogen values found in several fasts of 7 or more days are considered of sufficient importance in connection with the study of the fasting urine of our subject to be reproduced here and are accordingly recorded in table 26.

In this table the body-weight at the beginning of the fast is given for nearly every subject, and frequently for comparison the nitrogen excretion is included for the day prior to the fasting. The values for L. are first shown, these being followed by the nitrogen found in Succi's fasts. Unfortunately these latter values are not strictly comparable with the others, owing to the differences in methods of determination. Those found for Cetti can be relied upon, as can those for Beauté, Schenk, Tosca, and S. A. B. The values reported for Succi for the London and Naples fasts are undoubtedly somewhat low, but those for the Florence fast have been corrected by Munk. Even when these points are taken into consideration, the most striking feature in this whole group of results is the fact that the nitrogen excretion of our subject L. continues to be extraordinarily high to the fifteenth day of the fast, and, indeed, throughout the remainder of the fast the values are noticeably higher than those found in any other study of prolonged fasting.[1] Values as high, and even higher, are shown for Cetti for the 10 days of his fast, and also for the 7-day experiment of S. A. B., but in none of the longer fasts are such high values so continuously shown. In Succi's 30-day fast in Hamburg the value found for the last day (8.42 grams) was higher than that for the thirtieth day of the fasting experiment with L., but the earlier values were measurably lower. Another point of interest is that the general tendency is toward a low nitrogen output on the first day of the fast, with a higher nitrogen excretion on the subsequent one or two days. This characteristic is shown in the fasts with L., S. A. B., Tosca, and Beauté, and may easily be attributed to the protecting action of the body-storage of glycogen during the first few days.

One striking fact in connection with the high nitrogen output in L.'s fast is that on the fifteenth day there was a sudden fall of nearly 2 grams. An inspection of the values for the other subjects shows that in all of the fasts this sudden fall in the nitrogen excretion occurred at some point. Thus, in Succi's fast at Florence, there was a fall of 1 gram on the eighth day; in the London fast there was a fall of 1.2

[1]None of these subjects shows as absolute a minimum value for nitrogen excretion as was found on one day with Grafe's insane subject (Grafe, Zeitschr. f. physiol. Chemie, 1910, 65, p. 21), when the very low excretion of 1.057 grams of nitrogen was found. Since the body-weight of this subject was at the time 49.25 kilograms, this excretion would correspond to approximately 0.0215 gram of nitrogen per kilogram of body-weight. This surprisingly low value is difficult to explain, for while Grafe states that during the latter part of the experiment the urine was frequently spontaneously passed and hence the 24-hour periods could not be accurately determined, yet his discussion of this low value of 1.057 grams indicates that he believed it represented a 24-hour excretion of nitrogen. This remains the lowest value that we have as yet seen reported in any fasting observation on men or women.

grams on the seventh day; in the Naples fast, the nitrogen output fell 1.8 grams on the eighth day; in the Rome fast, it fell 1.8 grams on the ninth day; while in the Vienna fast, it fell 2.9 grams on the tenth day. With Cetti there was a fall in the nitrogen excretion of 2 grams on the eighth day; with Beauté the decrease was 1.1 grams on the seventh day; with Schenk it was 1 gram on the tenth day; with Tosca,

TABLE 26.—*Nitrogen eliminated in urine daily by fasting subjects.*

Day of fast.	L. 60.6 kilos.	Succi.						Cetti. 57.0 kilos.	Beauté. 65.6 kilos.	Schenk. 56.3 kilos.	Tosca.	S.A.B. 59.5 kilos.
		Florence. 63.3 kilos.	London. 55.8 kilos.	Naples. 63.6 kilos.	Rome. 65.1 kilos.	Vienna.	Hamburg. 78.5 kilos.					
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Last food day.	11.54	[1]17.85	.....	[2]8.99	9.13	.....	.....	13.49	16.45	.....	13.99	19.50
1st.....	7.10	15.19	.....	8.72	8.91	17.0	.....	13.55	10.51	.....	8.76	12.24
2d.....	8.40	12.13	[3]11.41	8.45	9.17	11.2	.....	12.59	14.38	8.41	8.38	12.45
3d.....	11.34	15.25	12.62	9.05	8.68	10.55	.....	13.12	13.72	6.50	10.73	13.02
4th.....	11.87	14.08	12.00	8.51	8.46	10.8	.....	12.39	13.72	7.78	9.40	11.63
5th.....	10.41	14.12	10.46	9.87	10.01	11.19	.....	10.70	(11.30)	7.86	7.87	10.87
6th.....	10.18	11.13	9.80	8.62	9.42	11.01	.....	10.10	10.77	7.82	7.73	10.74
7th.....	9.79	10.31	8.57	7.62	8.58	8.79	.....	10.89	9.67	7.13	6.11	10.13
8th.....	10.27	9.37	7.86	5.84	8.14	9.74	.....	8.90	9.52	6.20	7.70	.....
9th.....	10.74	8.56	7.50	6.90	6.35	10.05	.....	10.83	(9.39)	5.40	7.35	.....
10th.....	10.05	7.43	7.10	5.37	5.71	7.12	.....	9.47	8.38	4.38	6.80	.....
11th.....	10.25	8.67	6.51	5.10	4.94	6.32	.....	.....	8.49	5.17	6.14	.....
12th.....	10.13	7.88	6.86	6.19	5.11	6.84	.....	.....	8.77	5.38	6.97	.....
13th.....	10.35	3.86	6.14	4.83	4.78	5.14	.....	.....	(8.97)	8.11	5.62	.....
14th.....	10.43	5.87	5.95	3.83	4.41	4.66	.....	.....	7.78	5.96	4.08	.....
15th.....	8.46	5.66	5.36	4.14	2.83	5.05	.....	.....	.....	5.10	.....	.....
16th.....	9.58	6.05	5.35	3.24	3.15	4.23	.....	.....	.....	4.07	.....	.....
17th.....	8.81	6.78	5.40	5.01	3.32	5.4	.....	.....	.....	.....	.....	.....
18th.....	8.27	6.00	4.13	4.06	4.06	3.6	.....	.....	.....	.....	.....	.....
19th.....	8.37	5.54	3.98	3.49	3.82	5.7	.....	.....	.....	.....	.....	.....
20th.....	7.69	4.82	4.64	4.77	3.45	3.3	.....	.....	.....	.....	.....	.....
21st.....	7.93	4.27	4.00	5.37	.....	2.82	.....	.....	.....	.....	.....	.....
22d.....	7.75	3.52	5.16	.....	.....	.....	.....	.....	.....	.....	.....	.....
23d.....	7.31	5.23	4.66	.....	.....	.....	5.84	.....	.....	.....	.....	.....
24th.....	8.15	6.11	4.70	.....	.....	.....	6.41	.....	.....	.....	.....	.....
25th.....	7.81	6.65	4.32	.....	.....	.....	6.27	.....	.....	.....	.....	.....
26th.....	7.88	5.57	4.12	.....	.....	.....	6.18	.....	.....	.....	.....	.....
27th.....	8.07	5.90	3.81	.....	.....	.....	6.30	.....	.....	.....	.....	.....
28th.....	7.62	6.16	3.40	.....	.....	.....	4.44	.....	.....	.....	.....	.....
29th.....	7.54	4.49	4.13	.....	.....	.....	4.19	.....	.....	.....	.....	.....
30th.....	7.83	7.28	4.56	.....	.....	.....	8.42	.....	.....	.....	.....	.....
31st.....	6.94	.....	4.36	.....	.....	.....	.....	.....	.....	.....	.....	.....
32d.....	.....	.....	4.79	.....	.....	.....	.....	.....	.....	.....	.....	.....
33d.....	.....	.....	4.75	.....	.....	.....	.....	.....	.....	.....	.....	.....
34th.....	.....	.....	4.80	.....	.....	.....	.....	.....	.....	.....	.....	.....
34th.....	.....	.....	4.80	.....	.....	.....	.....	.....	.....	.....	.....	.....
35th.....	.....	.....	3.95	.....	.....	.....	.....	.....	.....	.....	.....	.....
36th.....	.....	.....	5.00	.....	.....	.....	.....	.....	.....	.....	.....	.....
37th.....	.....	.....	4.77	.....	.....	.....	.....	.....	.....	.....	.....	.....
38th.....	.....	.....	4.99	.....	.....	.....	.....	.....	.....	.....	.....	.....
39th.....	.....	.....	5.56	.....	.....	.....	.....	.....	.....	.....	.....	.....
40th.....	.....	.....	5.82	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1]The figures in this column are given for the first 10 days of the fast as corrected by Munk. The results for the remaining days have been increased in like proportion.

[2]Given by Ajello and Solaro as urea and here converted to nitrogen for purposes of comparison. Since the authors do not give the method employed, no attempt is here made to correct the figures.

[3]The results in this column were reported by the investigators as grains of urea, but are here converted to g

1.5 grams on the fourteenth day; and with S. A. B., 1.4 grams on the fourth day. These sudden drops were almost invariably permanent and were sometimes followed by a day on which even lower values were found. It is difficult to predict at what point this break in the nitrogen curve is likely to appear, and the irregularity of certain curves does not justify giving serious attention at present to this feature of the general course; nevertheless the fact that it is characteristic of all long fasting experiments is worthy of note.

The most accurate nitrogen determinations for the prolonged fasts shown in table 26 are unquestionably those made by Brugsch for Succi's fast at Hamburg. These values are somewhat lower than those found for L., although Succi's body-weight was 18 kilograms greater than that of our subject. In none of the fasting experiments do we find, save perhaps in the Hamburg fast, any indication of an increase in the nitrogen excretion near the end of the fast which may be considered as corresponding to the so-called "pre-mortal" rise which has been observed with many fasting animals, particularly with rabbits. It may be said, therefore, that the values found for L. follow much the same general course as the values found with the subjects of earlier fasting experiments, except that the level of the nitrogen excretion after the first 7 days was distinctly higher than with the other subjects.

Daily Excretion of Nitrogen.

Since L. had carefully preserved specimens of the urine from April 1 until the time of his arrival at the Nutrition Laboratory, we were able to obtain information as to the nitrogen excretion of this subject for 13 days preceding the fasting experiment. By reference to the results of these determinations (see table 23, page 238), it will be seen that in general the nitrogen excretion was on a moderately high level, averaging not far from 13 grams per day, and even exceeding this when the low value of 8.83 grams is excluded.

On his first day in Boston (April 10–11), the nitrogen excretion was 17.02 grams. This was the highest value found and doubtless resulted in part from the large beefsteak eaten by the subject on the night of his arrival. The nitrogen excretion subsequently decreased until on the last day before the fast it was but 11.54 grams. From April 10 until the beginning of the fast, therefore, the total nitrogen in the urine averaged over 14 grams per day. This is significant as indicating that L. was subsisting on a nitrogenous diet, which was quite inconsistent with his claim that he was a "low-proteid vegetarian."

The values for the nitrogen excretion for the whole experiment, including not only those for the fasting period, but for the food days prior to and following the fast, are given in table 27.

As noted in the comparison with other fasting subjects, two striking features of these values for the total nitrogen excretion are the immedi-

ate decrease with the beginning of the fast and the continuance of the high values until after the fourteenth day. This decrease in the nitrogen excretion in the first few days of the fasting period has already been explained as being due to the relatively large katabolism of glycogen on those days. The average nitrogen excretion for the first 10 days of the fast was over 10 grams. The highest value (11.87 grams) in the whole of the series was found on the fourth day, and the lowest value (6.94 grams) on the thirty-first day. That the lowest value was

TABLE 27.—*Nitrogen excreted in urine, per day and per kilogram of body-weight, in experiment with L.*

Date.	Day of fast.	Nitrogen excreted.		Date.	Day of fast.	Nitrogen excreted.	
		Per day.	Per kilogram of body-weight per day.			Per day.	Per kilogram of body-weight per day.
1912.		*gm.*	*gm.*	1912.		*gm.*	*gm.*
Apr. 11–12..	.....	15.92	0.264	Apr. 30–May 1..	17th...	8.81	0.169
12–13..	.....	14.48	.238	May 1–2.....	18th...	8.27	.160
13–14..	.....	11.54	.190	2–3.....	19th...	8.37	.163
14–15..	1st...	7.10	.118	3–4.....	20th...	7.69	.151
15–16..	2d....	8.40	.142	4–5.....	21st ...	7.93	.156
16–17..	3d....	11.34	.195	5–6.....	22d....	7.75	.154
17–18..	4th...	11.87	.207	6–7.....	23d....	7.31	.146
18–19..	5th...	10.41	.184	7–8.....	24th...	8.15	.164
19–20..	6th...	10.18	.181	8–9.....	25th...	7.81	.158
20–21..	7th...	9.79	.176	9–10.....	26th...	7.88	.160
21–22..	8th...	10.27	.186	10–11.....	27th...	8.07	.165
22–23..	9th...	10.74	.196	11–12.....	28th...	7.62	.157
23–24..	10th...	10.05	.185	12–13.....	29th...	7.54	.156
24–25..	11th...	10.25	.190	13–14.....	30th...	7.83	.163
25–26..	12th...	10.13	.189	14–15.....	31st...	6.94	.146
26–27..	13th...	10.35	.193	15–16.....	.....	4.83	.102
27–28..	14th...	10.43	.196	16–17.....	.....	3.81	.081
28–29..	15th...	8.46	.160	17–18.....	.....	[1]2.75	[1].058
29–30..	16th...	9.58	.182				

[1]Determined in urine for about 22 hours.

but 0.16 gram lower than that found on the first day may be explained by the fact that on the first day L.'s energy requirement was in part met by the combustion of about 70 grams of glycogen (see table 63, page 412). On the last day the katabolism was essentially a protein-fat katabolism, unassisted by the combustion of any measurable amount of carbohydrate. During the 31-day fast this subject actually excreted 277.32 grams of nitrogen in the urine, thus averaging 8.95 grams of nitrogen per day. This would correspond to 1,664 grams of protein, or 8,319.60 grams of flesh. Since the entire loss in body-weight of this subject was 13.25 kilograms, it can be seen that 63 per cent of the total loss may be accounted for in flesh katabolized.

Although this is primarily a study of the excretion of nitrogen during fasting, the values found for the 3 days subsequent to the fast have a certain interest. During these days the subject took an almost protein-free[1] diet, consisting of fruit juices and honey. The large amount of carbohydrate contained in this diet immediately protected the protein in the body and in consequence there was a continually decreasing nitrogen excretion, until on the last day we have the lowest amount found with this subject, namely, 2.75 grams. This 22-hour value is actually somewhat lower than that found with Beauté by Cathcart in a 3-day experiment with a starch-cream diet of Folin—Beauté, with a body-weight of not far from 58 kilograms, showing a minimum nitrogen output of 2.84 grams. Since L. had a body-weight at this time of only 47.5 kilograms, it would perhaps be expected that his nitrogen excretion would be much lower than that of Cathcart's subject; it should be noted, however, that his total nitrogen level was considerably higher than that shown by Beauté.

The values found for our subject L. on these days of food following the fast have a special interest, in that they show that the excess of carbohydrate in the diet acted as a great protection of the body protein, and hence we have here probably the nearest to the minimum protein requirement of this man, corresponding to the "Abnutzungsquote" of Rubner.

Nitrogen Excretion per Kilogram of Body-weight.

We have no information as to the fluctuations in the body-weight prior to the arrival of the subject at the laboratory, but accurate observations were made from April 11 to the end of the experiment, and the nitrogen per kilogram of body-weight may thus be computed for that period. These values are also given in table 27. On the first day of the fast the nitrogen output per kilogram of body-weight was very low, being only 0.118 gram. It then rose regularly until it reached a maximum on the fourth day of 0.207 gram. Thereafter there was, in general, a steady fall, with two minima of 0.146 on the twenty-third and the thirty-first

[1]To aid in indicating the kinds and amounts of food eaten on the first two days of food following the fast, the estimated amounts and composition of food eaten are tabulated herewith:

Date.	Kind of food.	Amount eaten.	Protein.	Fat.	Carbohydrates.	Nitrogen.
1912.		gm.	gm.	gm.	gm.	gm.
May 15–16	Lemons.....	100	1.00	0.70	8.5	0.16
	Oranges.....	450	3.60	.90	52.2	.59
	Honey.....	311	1.24	....	252.5	.19
	Grape juice...	1072	....	....	178.6	....
	Total....	....	5.84	1.60	491.8	0.94
May 16–17	Lemon juice..	80	....	....	7.8	....
	Honey.....	139	0.55	....	112.8	0.08
	Orange juice..	1128	6.05	....	128.1	1.01
	Total....	....	6.60	....	248.7	1.09

days respectively. After food was again taken, the nitrogen excretion decreased to the surprisingly low value of 0.058 gram per kilogram of body-weight.

COMPARISON OF METHODS FOR DETERMINING TOTAL NITROGEN AND AMMONIA-NITROGEN.

The microchemical methods had been developed just previous to this fasting experiment and were therefore used by Mr. H. L. Higgins for determining the total nitrogen and the ammonia-nitrogen. The total nitrogen was also determined by the Kjeldahl method and the ammonia-nitrogen by the old Folin method, both determinations being made by Miss E. B. Babcock. These analyses of the fasting urines were therefore the first control analyses which had been made outside of the Folin laboratory. Both the Kjeldahl method and the Folin microchemical method were frequently tested by determining the nitrogen of

TABLE 28.—*Comparison of the determinations of nitrogen and ammonia-nitrogen by former methods and the new microchemical methods of Folin.*

Date.	Day of fast.	Total nitrogen.		Ammonia-N.	
		Kjeldahl method.	Folin micro method.	Folin method (original).	Folin micro method.
1912.		*gm.*	*gm.*	*gm.*	*gm.*
Apr. 15–16	2d	.....	.....	0.60	0.60
16–17	3d	11.34	10.26	.95	.95
17–18	4th	11.87	11.46	1.40	1.40
18–19	5th	10.41	9.94	1.60	1.63
19–20	6th	10.18	9.91	1.67	1.69
20–21	7th	9.79	9.30	1.52	1.56
21–22	8th	10.27	9.91	1.62	1.68
22–23	9th	10.74	10.74	1.70	1.68
23–24	10th	10.05	10.02	1.57	1.60
24–25	11th	10.25	10.45	1.56	1.60
25–26	12th	10.13	10.11	1.47	1.51
26–27	13th	[1]9.91	10.00	[1]1.45	[1]1.52
27–28	14th	10.43	10.25	1.57	1.61
28–29	15th	8.46	8.58	1.43	1.46
29–30	16th	9.58	9.47	1.91	1.97
Apr. 30–May 1	17th	8.81	8.77	1.90	1.93
May 1–2	18th	8.27	8.45	1.80	1.80
2–3	19th	8.37	8.11	1.76	1.81
4–5	21st	7.93	7.90	....	....
7–8	24th	8.15	8.24	1.52	1.55
8–9	25th	7.81	7.91	1.51	1.52
9–10	26th	7.88	8.00	1.42	1.43
10–11	27th	8.07	7.99	1.36	1.39
11–12	28th	7.62	7.46	1.28	1.29
12–13	29th	7.54	7.64	1.32	1.32
13–14	30th	7.83	7.60	1.32	1.32
14–15	31st	6.94	6.83	1.25	1.22
15–16	.....	3.72	3.64	.52	.53
16–17	.....	3.81	3.98	.36	.36

[1]For total amounts of nitrogen and ammonia-N on this day, see table 29.

known substances, such as ammonium-sulphate, ammonium ferrous sulphate, urea, and uric acid. We were thus assured of the accuracy of the methods. Since the Folin microchemical methods played such an important role in these analyses, particularly in an economical distribution of the available urine, it seems desirable to publish the results of the control tests. Accordingly, in table 28, the values obtained for the total nitrogen by the Kjeldahl method are compared with those secured by the microchemical methods; the values for the ammonia-nitrogen obtained with the new and old Folin methods are also compared. As will be seen, the results of such comparison are most satisfactory. We wish again to emphasize the great value of these methods, particularly when there is urgent necessity for the use of small samples.

THE PARTITION OF THE NITROGEN EXCRETION.

While the total nitrogen excretion in the urine of a fasting man has a general interest, more particularly in the apportionment of the total energy requirement and the energy output among the various factors, protein, carbohydrate, and fat, a clear understanding of the nature of the disintegration of the nitrogenous material is obtained only when a partition of the nitrogen excretion is made according to the analytical scheme of Folin. Fortunately, with all of the samples of urine collected for the 31 days of the fast we were able to secure a complete partition of the nitrogen, with the single exception of the determination of the total purines; we were, however, able to determine the uric acid-nitrogen. This partition included the determination of the total nitrogen, and the nitrogen from urea, ammonia, uric acid, creatinine preformed, and total creatinine. The nitrogen undetermined is given as "rest nitrogen." Furthermore, since Folin has shown the great significance of the proportionate distribution of the nitrogen derived from these various sources, we have computed the percentage of the total nitrogen in these nitrogenous constituents of the urine. The values for each day, expressed in grams and in percentages of total nitrogen, are given in table 29.

Urea.

With the microchemical method of Folin, the urea-nitrogen in the fasting urines could be determined with great accuracy. The determinations were accordingly made by Mr. Higgins for the 31 days of the fasting period and for the 3 days following the fast. The results are given in table 29, together with the percentage of urea-nitrogen in terms of total nitrogen.

In general the course of the excretion of the urea-nitrogen follows quite closely that of the total nitrogen. The regular increase shown in the first 3 days for the total nitrogen is also apparent here; the

smallest amount of urea-nitrogen (4.84 grams) is likewise found on the last day of the fast, but unlike the total nitrogen is considerably smaller than the excretion for the first day of the fast. The percentage of urea-nitrogen shown for the first few days, *i. e.*, approximately 80 per cent, is distinctly lower than that found with normal urine, Folin[1] giving as

TABLE 29.—*Partition of nitrogen excreted in urine in experiment with L.*

Date.	Day of fast.	Excretion of nitrogen.						
		Total nitrogen.	Urea-N.	Ammonia-N.	Uric acid-N.	Creatinine-N (preformed).	Total creatinine-N.	Rest-N.
1912.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Apr. 11–12	.....	15.92	....	0.67	.....	....	....	....
12–13	.....	14.48	....	.65	.....	....	....	....
13–14	.....	11.54	....	.59	....	....	....	....
14–15	1st....	7.10	5.68	.41	0.112	0.51	0.48	0.42
15–16	2d.....	8.40	6.69	.60	.049	.46	.46	.60
16–17	3d.....	11.34	9.11	.95	.042	.46	.55	.69
17–18	4th....	11.87	9.03	1.40	.044	.42	.54	.86
18–19	5th....	10.41	7.58	1.62	.059	.41	.51	.64
19–20	6th....	10.18	7.36	1.68	.097	.39	.52	.52
20–21	7th....	9.79	7.02	1.54	.112	.38	.49	.63
21–22	8th....	10.27	7.45	1.65	.108	.38	.50	.56
22–23	9th....	10.74	7.83	1.69	.099	.37	.50	.62
23–24	10th....	10.05	7.44	1.59	.118	.37	.49	.41
24–25	11th....	10.25	7.66	1.58	.116	.37	.49	.40
25–26	12th....	10.13	7.43	1.49	.154	.37	.49	.57
26–27	13th....	10.35	7.69	1.55	.093	.35	.48	.54
27–28	14th....	10.43	7.69	1.59	.125	.33	.44	.59
28–29	15th....	8.46	6.18	1.45	.071	.30	.38	.38
29–30	16th....	9.58	6.71	1.94	.099	.32	.42	.41
Apr. 30–May 1	17th....	8.81	5.95	1.92	.100	.31	.40	.44
May 1– 2	18th....	8.27	5.70	1.80	.122	.34	.41	.24
2– 3	19th....	8.37	5.58	1.79	.130	.30	.38	.49
3– 4	20th....	7.69	5.36	1.58	.115	.31	.38	.26
4– 5	21st....	7.93	5.54	1.57	.112	.31	.38	.33
5– 6	22d.....	7.75	5.60	1.51	.110	.31	.36	.17
6– 7	23d.....	7.31	5.01	1.49	.097	.34	.36	.35
7– 8	24th....	8.15	5.92	1.54	.114	.30	.34	.24
8– 9	25th....	7.81	5.43	1.52	.098	.28	.35	.41
9–10	26th....	7.88	5.62	1.43	.063	.29	.36	.41
10–11	27th....	8.07	5.90	1.38	.089	.29	.35	.35
11–12	28th....	7.62	5.46	1.29	.095	.28	.34	.44
12–13	29th....	7.54	5.55	1.32	.101	.29	.35	.22
13–14	30th....	7.83	5.53	1.32	.106	.29	.33	.54
14–15	31st....	6.94	4.84	1.24	.122	.30	.32	.42
15–16	.....	4.83	3.21	.69	.140	.35	.37	.42
16–17	.....	3.81	2.69	.36	.144	.34	.34	.28
[1]17–18	.....	2.75	1.54	.35	.111	.35	.33	.42

[1]The amounts for this day were determined in the urine for about 22 hours.

an average for his subjects 87.5 per cent of the total nitrogen in the form of urea. The percentage of the urea-nitrogen then falls rapidly until on the fifth day it is but 72.82 per cent. The lowest percentage found

[1]Folin, Am. Journ. Physiol., 1905, **13**, p. 62.

TABLE 29.—*Partition of nitrogen excreted in urine in experiment with L.*—Continued.

Date.	Day of fast.	Proportion of total nitrogen in—					
		Urea.	Ammonia.	Uric acid.	Creatinine (preformed).	Total creatinine.	Rest-N.
1912.		*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
Apr. 11–12	.....	.....	4.21	....	....	....	....
12–13	.....	.....	4.49	....	....	....	....
13–14	.....	.....	5.11	....	....	....	....
14–15	1st....	80.00	5.77	1.58	7.18	6.76	5.89
15–16	2d.....	79.64	7.14	.58	5.48	5.48	7.16
16–17	3d.....	80.33	8.38	.37	4.06	4.85	6.07
17–18	4th....	76.07	11.79	.37	3.54	4.55	7.22
18–19	5th....	72.82	15.56	.57	3.94	4.90	6.15
19–20	6th....	72.30	16.50	.95	3.83	5.11	5.14
20–21	7th....	71.71	15.73	1.14	3.88	5.01	6.41
21–22	8th....	72.54	16.07	1.05	3.70	4.87	5.47
22–23	9th....	72.90	15.73	.92	3.44	4.66	5.79
23–24	10th....	74.03	15.82	1.17	3.68	4.88	4.10
24–25	11th....	74.73	15.41	1.13	3.61	4.78	3.95
25–26	12th....	73.35	14.71	1.52	3.65	4.84	5.58
26–27	13th....	74.30	14.98	.90	3.38	4.64	5.18
27–28	14th....	73.73	15.24	1.20	3.16	4.22	5.61
28–29	15th....	73.05	17.14	.84	3.55	4.49	4.48
29–30	16th....	70.04	20.25	1.03	3.34	4.38	4.30
Apr. 30–May 1	17th....	67.54	21.79	1.14	3.52	4.54	4.99
May 1– 2	18th....	68.92	21.77	1.48	4.11	4.96	2.87
2– 3	19th....	66.67	21.39	1.55	3.58	4.54	5.85
3– 4	20th....	69.70	20.55	1.50	4.03	4.94	3.31
4– 5	21st....	69.86	19.80	1.41	3.91	4.79	4.14
5– 6	22d.....	72.26	19.49	1.42	4.00	4.65	2.18
6– 7	23d.....	68.54	20.38	1.33	4.65	4.92	4.83
7– 8	24th....	72.64	18.90	1.40	3.68	4.17	2.89
8– 9	25th....	69.52	19.46	1.25	3.59	4.48	5.29
9–10	26th....	71.32	18.15	.80	3.68	4.57	5.16
10–11	27th....	73.12	17.10	1.10	3.59	4.34	4.34
11–12	28th....	71.66	16.93	1.25	3.67	4.46	5.70
12–13	29th....	73.61	17.51	1.34	3.85	4.64	2.90
13–14	30th....	70.63	16.86	1.35	3.70	4.21	6.95
14–15	31st....	69.74	17.87	1.76	4.32	4.61	6.02
15–16	.....	66.46	14.28	2.90	7.25	7.66	8.70
16–17	.....	70.60	9.45	3.78	8.92	8.92	7.25
[1]17–18	.....	56.00	12.73	4.04	12.73	12.00	15.23

[1]The amounts for this day were determined in the urine for about 22 hours.

during the last 26 days was 66.67 per cent on the nineteenth day and the highest on the eleventh day of 74.73 per cent. The average value for these days was 71.5 per cent, with a distinct tendency towards constancy. Upon the resumption of food, there was at first no marked disturbance in this ratio, but on the third day the percentage of urea-nitrogen decreased to the low value of 56 per cent, this value being found at the time that only 2.75 grams of nitrogen were excreted in the urine. These low values in the percentage of urea-nitrogen are perfectly comparable with those found by Folin on subjects subsisting

on a starch-cream diet, with an excretion of nitrogen corresponding to not far from 4 to 5 grams per day.

These figures are also substantiated by the observations of Cathcart. While he found in the first 3 days of Beauté's fast that the urea-nitrogen averaged not far from 87 per cent instead of the 80 per cent found with our subject L., and that the values also averaged somewhat higher for the remainder of the fast, nevertheless the percentage fell as low as 71 per cent on the eighth day of the fast. On the food days following the fast, the urea-nitrogen fell to 61.97 per cent on the day when the minimum nitrogen excretion was observed.

E. and O. Freund found in their observations on Succi that the urea-nitrogen was 82 per cent or more of the total nitrogen excretion for the first two weeks of the fast. There was then a rapid fall in the percentage until but 56 and 58 per cent of urea-nitrogen were found on the last 2 days. Brugsch's observations on Succi in Hamburg show that for the last 8 days of the 30-day fast, the urea-nitrogen was not far from 60 per cent of the total nitrogen.

Van Hoogenhuyze and Verploegh, in their observations on Tosca, note most irregular proportions of urea-nitrogen. The percentages of urea-nitrogen computed by us from their data are as follows, the day of the fast being given in parentheses: (1) 68.84; (2) 79.11; (3) 93.29; (4) 84.90; (5) 66.07; (6) 59.00?; (7) 81.02; (8) 84.42; (9) 88.43; (10) 87.65; (11) 85.84; (12) 86.80; (13) 86.84; (14) 88.73. On the sixth day the low value of 59 per cent is from data questioned by the authors. In the light of other fasting studies, there is no obvious explanation for the unusually high average value, especially for the last 8 days of the fast.

From all the evidence it can be seen that in general during fasting the urea output approximately parallels that of the total nitrogen, there being a decided increase on the first few days of fasting, followed by a decrease. In practically every instance when there is a fluctuation in the total nitrogen output, this is paralleled by the urea-nitrogen. It would thus appear that the determining factor in the fluctuations of the total nitrogen is probably the proportion of urea-nitrogen, and not the gross alterations in the other factors. The variation in the percentage distribution can, however, be intelligently treated only after a consideration of the changes in the output of ammonia-nitrogen.

Ammonia.

The ammonia-nitrogen, on account of its great significance in considering the products of defective fat katabolism, was determined by both the old and the new Folin methods. The results of these two series of determinations are given in table 28, page 253. An average of these two series of values is also given in table 29.

Normal urine always contains a relatively small amount of ammonia, and the amounts found for L. on the 3 days prior to the fast were

approximately those which would be noted for normal individuals subsisting on a diet containing about 15 grams of nitrogen. The ammonia-nitrogen formed not far from 4.5 per cent of the total nitrogen excretion per day. At the beginning of the fasting period the amount of ammonia-nitrogen excreted fell somewhat, and not until the third day do we find values exceeding those obtained before the fast. On the fourth day it rose quite sharply to 1.40 grams and then continued to rise steadily, with slight fluctuations, until the maximum value of 1.94 grams was reached on the sixteenth day. Thereafter it slowly and quite regularly decreased until the end of the experiment, the excretion of ammonia-nitrogen on the last day being 1.24 grams. This gradual increase and decrease was exactly that observed by Cathcart, although the maximum value with his subject was observed on the eighth day, while with L. it did not appear until the sixteenth day. Brugsch found the excretion of ammonia-nitrogen quite regular, ranging between 1.26 grams and 1.72 grams in the last 8 days of Succi's fast in Hamburg.

Since the amount of ammonia-nitrogen would normally be expected to fluctuate somewhat with the fluctuations in the total nitrogen excretion, the percentage of ammonia-nitrogen in the total nitrogen must be considered. On this basis the minimum percentage (5.77 per cent) is found on the first day of the fast, with the maximum (21.79 per cent) on the seventeenth day. Even on the percentage basis the ammonia-nitrogen tends to increase until the middle of the fast and then slowly to decrease, although towards the end it was still 10 per cent or more larger than it was prior to the fasting period.

It is clear, therefore, that there was some factor which stimulated the excretion of ammonia-nitrogen. From previous experience with fasting subjects, it is obvious that this increase in the excretion was due to the organic acids, chiefly the β-oxybutyric acid resulting from defective fat katabolism. The large excretion of ammonia therefore undoubtedly corresponds to an increasing acidosis, the production of the ammonia being a protective action on the part of the body to overcome the effect of the acids. The amounts of ammonia-nitrogen found for L. during fasting were measurably greater than those observed by Cathcart for his subject and the percentage of the total nitrogen was also considerably greater. These values would therefore imply that L. had a somewhat greater acidosis than had Beauté in Cathcart's research.

The results of the observations of E. and O. Freund on Succi are diametrically opposed to the values found by Cathcart on Beauté, Brugsch on Succi, and by us with L., for both the absolute amount and the percentage of the total nitrogen found, and one is inclined to question somewhat the technique of the Freunds. While the observations of Bonniger and Mohr[1] on the fasting woman Schenk are complicated by the

[1]Bonniger and Mohr, Zeitschr. f. exp. Path. u. Therapie, 1906, 3, p. 675.

introduction of amino-acids, their results should also be cited. The absolute amounts of ammonia-nitrogen excreted varied from 0.40 gram on the second fasting day to 1.84 gram on the seventh day of fasting. The percentage of ammonia-nitrogen in the total nitrogen varied from 5.28 per cent on the second day to the high value of 30.57 per cent on the sixteenth day of the fast. In general, these values are not unlike those observed by us on our subject L.

If we compare the values obtained with L. for the urea-nitrogen and the ammonia-nitrogen, it is evident that the ammonia-nitrogen was formed at the expense of urea-nitrogen, for whenever the values for the urea-nitrogen decrease, those for the ammonia-nitrogen increase, and *vice versa*. A fact of particular interest is the rapid return to a small excretion of ammonia-nitrogen with the taking of food by the subject. Even on the first day with food, the ammonia-nitrogen fell to 0.69 gram. On subsequent days the absolute values decreased to 0.36 gram and 0.35 gram respectively, though still forming 10 to 12 per cent of the total nitrogen. It is obvious, therefore, that, with the ingestion of a large amount of carbohydrate and a decrease in the acidosis, there was no necessity for an excessive ammonia-nitrogen excretion.

Uric Acid.

In the earlier fasting experiments at Wesleyan University, material was available for only a few determinations of the uric acid, which were made possible through the courtesy of Professor Lafayette B. Mendel, of Yale University. In this experiment with L. the determinations of uric acid were personally made by Professor Otto Folin, by his new colorimetric method,[1] small specimens of the 24-hour urine being sent to the Harvard Medical School daily for analysis. The results of his determinations, expressed as uric-acid nitrogen, are given in table 29.

No determinations of the uric-acid nitrogen were made prior to the fasting period. During the fast the minimum amount of 0.042 gram was obtained on the third day and the maximum of 0.154 gram on the twelfth day, the amounts varying considerably throughout the entire fasting period.

With the origin of uric acid still the subject of considerable critical debate, particularly between Sivén[2] on the one hand and Mareš[3] and his colleagues on the other, it can be seen that although the general tendency is for physiologists to uphold the views of Mareš,[4] it is difficult to interpret the values for the uric-acid excretion obtained in this fast on any of the present hypotheses as to its origin. That it is a deriva-

[1]Folin and Denis, Journ. Biol. Chem., 1913, **14**, p. 95.
[2]Sivén, Archiv f. d. ges. Physiol., 1912, **146**, p. 499.
[3]Mareš, Archiv f. d. ges. Physiol., 1912–1913, **149**, p. 275. See also Smetánka, Archiv f. d. ges. Physiol., 1911, **138**, p. 217; *ibid.*, 1912–1913, **149**, p. 287.
[4]Mareš, Archiv f. d. ges. Physiol., 1910, **134**, pp. 59–102.

tion of nuclein katabolism is undoubtedly true. Beyond this universally accepted fact, the evidence as to the influence of intestinal, glandular, kidney, and muscular activity is much debated.

In previous fasting experiments it has been shown that the glandular activity, at least so far as the digestive organs are concerned, is at a minimum,[1] and hence we should expect to find that if any considerable proportion of the uric acid were obtained as the result of glandular activity, there would be a minimum uric-acid nitrogen excretion during the fast. Aside from the admittedly low values on the second to the fifth days of the fasting experiment with L., this was not the case, for there are many days during the fast on which there was fully as much uric-acid nitrogen, if not indeed more, than one would expect to find with a normal individual subsisting on a purine-free diet.[2]

After L. had taken food, there was a slight increase in the total uric-acid nitrogen excretion from 0.122 gram, which was obtained on the last day of the fast, to 0.140 gram on the first day with food. Ordinarily this would not be considered as a substantial increase in the total uric-acid nitrogen excretion, and yet in recent controversial papers, Mareš has pointed out that a 10 per cent increase is not to be ignored and that it does represent an actual increase. While according to Mareš, the ingestion of food which stimulates the digestive glands to their greatest activity is most productive of an increase in the excretion of uric acid, nevertheless, Smetánka has found that such an excretion took place even with honey. Inasmuch as the food taken by L. was in large part carbohydrate, a portion of the diet being honey, it is not impossible to believe that there may have been a positive increase in the uric-acid nitrogen as a result of the ingestion of this food. This is the more credible if we give heed to Smetánka's criticism that 24-hour periods are not best suited to the study of this problem, as the influence of the activity of the digestive glands disappears rapidly after the ingestion of food.

During the fasting period, the percentage of the total nitrogen in the form of uric-acid nitrogen likewise underwent considerable fluctuation, approximately paralleling the absolute amount of this constituent. The percentage value shows a distinctly increased uric-acid nitrogen excretion in the post-fasting period, rising to 4.04 per cent, and while the evidence is by no means complete, this may well be interpreted as an index of an increased glandular (digestive) activity.

Cathcart also determined the uric-acid nitrogen excretion for his subject, using the method of Hopkins-Folin. During the first half of the fast he found a distinctly lower value for the uric-acid nitrogen than in the preceding food period, but there was a continual tendency for this form of nitrogen to increase as the fast progressed. With the taking of food there was an increase in the uric-acid nitrogen—at

[1]Luciani, Das Hungern, Hamburg and Leipsic, 1890, p. 44.
[2]Folin, Am. Journ. Physiol., 1905, **13**, p. 62.

least on the first day—followed by 4 days with the same excretion as in the last period of the fast. Thus, in Beauté's fast there was a definite tendency towards regularity[1] in the excretion of the uric-acid nitrogen, inasmuch as there was from the beginning to the end a regular, though slight, increase—a regularity that was by no means paralleled by the observations on L.

While the values found for L. were decidedly variable, yet in several points they strikingly confirm the earlier observations. Thus the marked fall on the second fasting day, followed by a low excretion for several days and a subsequent rise, with a higher value on the first food day than that shown on the last fasting day, are all in agreement with the observations of Cathcart with Beauté, and of Van Hoogenhuyze and Verploegh in their 14-day experiment with Tosca.

The rapid fall in the uric-acid nitrogen excretion on the second day has also been observed in shorter fasts by Schreiber and Waldvogel,[2] by Hirschstein,[3] and by Feldmann.[4] Scaffidi,[5] in experimenting on the purine metabolism in fasting, concluded that with those animals with which there was a formation of oxidative uric acid, the uric-acid nitrogen decreased during starvation and there was no regularity in the relation of total uric-acid nitrogen to the total nitrogen.

This decrease in the uric-acid excretion of L. was coincident with that period of the fast when the supply of glycogen was rapidly being depleted and the subsequent increase followed sharply the incidence of the protein-fat katabolism characteristic of the remainder of the fast. The cessation of the glandular activity of digestion on the first few days may explain the fall in the uric-acid nitrogen, but the subsequent increase can only be explained by an increase in the katabolism of the active protoplasmic tissue. The fact that this excretion does not remain constant, or at least does not regularly increase or decrease, is indeed difficult to explain, since there are no obvious reasons for assuming that the changes in the amount of the excretion of uric-acid nitrogen are due to corresponding changes in the rate of destruction of the active protoplasmic tissue. Indeed, if we observe the total creatinine excretion, the regular decrease of that urinary constituent would imply a proportional regularity in the rate of destruction of the active protoplasmic tissue. It is evident that the values obtained for the excretion of the uric-acid nitrogen in this fasting experiment offer no proof of the validity of any of the present-day conceptions as to the origin of endogenous uric-acid excretion.

[1]Regularity in the uric-acid excretion as the fast progressed was also noted for the greater part of the experiment with Tosca by Van Hoogenhuyze and Verploegh (*loc. cit.*) and with Succi in Vienna by E. and O. Freund (Wiener klin. Rundsch., 1901, **15**, p. 69). Brugsch (Zeitschr. f. exp. Path. u. Therapie, 1905, **1**, p. 419) found very constant values for the purine-nitrogen during the last eight days of Succi's Hamburg fast.

[2]Schreiber and Waldvogel, Arch. f. exp. Path. u. Pharm., 1899, **42**, p. 69.

[3]Hirschstein, Arch. f. exp. Path. u. Pharm., 1907, **57**, p. 229.

[4]Feldmann, cited by Sivén, Archiv. f. d. ges. Physiol., 1912, **146**, p. 499.

[5]Scaffidi, Biochem. Zeitschr., 1911, **33**, p. 153.

Creatinine.

As a result of Folin's fundamental observations on the partition of the nitrogen of normal urines, special stress was laid upon the determination of the creatinine existing in the urine of this fasting man, Folin having emphasized the fact that the total creatinine may be looked upon as an index of the total tissue metabolism.[1] Immediately after Folin's papers had appeared, a large number of researches on the creatinine in urine were reported, and observations were simultaneously made in several laboratories which implied the presence of creatine in urine under certain conditions, particularly in pathological cases and during fasting.

Folin's analytical scheme enabled the direct determination of creatine, the creatinine being first determined, and subsequently any creatine in the urine was converted to creatinine by heating with acid for 3 hours. These results were reported by him as creatinine preformed and total creatinine, the difference in the two values being estimated to be a measure of the creatine expressed in terms of creatinine.

There is little of positive value to be said regarding the determinations of creatine or creatinine in fasting experiments prior to the introduction of the Folin method, hence Baldi's[2] observations as well as those of the Freunds[3] on Succi can have but little quantitative interest. One of the first studies made after the Folin method was put forth is that of Van Hoogenhuyze and Verploegh on Tosca.[4] The considerable decrease in the creatinine obtained by them at the beginning of the fast, followed by an increase after food, shows (in part at least) that only preformed creatinine was determined, and hence their values correspond more nearly to the values reported for our subject as preformed creatinine.

In the experiments at Wesleyan University, the total creatinine was invariably found to be somewhat higher in the fasting periods than the preformed creatinine, the difference disappearing when food was taken, and thus the conclusion was drawn that creatine was to be found regularly in the urine of fasting subjects. This observation was simultaneously made and published by Cathcart.[5] Laying special emphasis upon the difference between preformed and total creatinine, Cathcart discussed at considerable length the appearance of creatine in the urine. Although our interpretation of the presence of creatine in the urine differs considerably from that of Cathcart, the fact remains that since that time considerable research has been carried out on both creatinine and creatine excretion, and hence an observation of the amount excreted by our fasting subject was particularly desirable.

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[1]Folin, Am. Journ. Physiol., 1905, **13**, pp. 66 and 117.
[2]Baldi, Sperimentale, March 1889; Centrlb. f. klin. Med., 1889, **10**, p. 651.
[3]E. and O. Freund, Wiener klin. Rundsch., 1901, **15**, pp. 69 and 91.
[4]Van Hoogenhuyze and Verploegh, Zeitschr. f. physiol. Chemie, 1905, **46**, p. 415.
[5]Cathcart, Biochem. Zeitschr., 1907, **6**, p. 109.

The only other fasts on human subjects in which the Folin methods have been used are the two 7-day fasts reported by Howe, Mattill, and Hawk.[1] Here, as in our experiments, preformed creatinine and total creatinine were determined without prior treatment to remove aceto-acetic acid. The large amount of creatine-nitrogen found by them on the first fasting day with their subject E., namely, 0.269 gram, is wholly inexplicable, being larger than any observation with which we are familiar. After the first 3 days there was a regular decrease in the creatine-nitrogen excretion, until on the seventh day it was practically nothing. With subject H. they found an increasing creatine-nitrogen excretion for the first 4 days, followed by a decrease. It is thus seen that, as the result of determinations by the Folin method, several observers have noted that the total creatinine is greater than the preformed creatinine.

In interpreting the increase in the creatinine excretion in the fasting experiments at Wesleyan University as being due to the presence of creatine, attention was especially directed[2] to the possible influence upon the Jaffé reaction of substances other than creatine and creatinine. Immediately after this publication had appeared, and in subsequent visits to foreign laboratories where work upon creatine and creatinine was being carried out, I was assured that no substance existing in either fasting or diabetic urine appreciably affected the reaction and that this interpretation of the difference between preformed creatinine and total creatinine was undoubtedly justifiable. Accordingly, in presenting the results obtained with L., the assumption has been made that a difference between preformed creatinine and total creatinine, as ordinarily determined, could be taken as an index of the presence of creatine.

The creatinine determinations in these fasting urines were made by Miss Alice Johnson, under the immediate supervision of Dr. A. W. Peters, numerous control tests being made with samples of pure creatinine kindly furnished by Professor Otto Folin. The preformed creatinine was determined according to the usual Folin method and in no instance was abnormal fading or alteration in color noted. Furthermore, in the light of recent investigations, it is important to note that no special treatment was given for the removal of acetone bodies which would possibly have affected the color. After the determination of the preformed creatinine, the total creatinine was determined by heating another specimen of the urine with hydrochloric acid for 3 hours on an electric plate to convert the creatine to creatinine. The readings were carefully controlled and the illumination of the colorimeter was given special attention. The results as found by these two processes are expressed as nitrogen of creatinine preformed and total creatinine

[1]Howe, Mattill, and Hawk, Journ. Am. Chem. Soc., 1911, **33**, p. 568.
[2]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 395.

and are given in table 29. As with the earlier fasting experiments, there was a difference between the creatinine preformed and the total creatinine as thus measured.

At the time these analyses were made, we were firmly of the opinion that the results obtained by such analysis would represent quantitatively the amount of creatine in urine, expressed as creatinine. Since these investigations were carried out, two papers have appeared which lead us to question the quantitative relations exhibited in the values here given. Greenwald,[1] in his work on diabetic urines, considers the effect of the acetone bodies upon the Jaffé reaction and concludes that urine containing aceto-acetic acid and acetone will give correct results for creatinine by the Folin method only after the removal of these substances. More recently Graham and Poulton[2] have studied the influence of aceto-acetic acid on the estimation of creatinine and have called into question the interpretation of the difference between preformed and total creatinine as reported in fasting experiments and in experiments with carbohydrate starvation. They conclude that "acetone and β-oxybutyric acid, if present in amounts comparable to those which usually occur in urine, produce practically no error in the estimation of creatinine." They furthermore state that aceto-acetic acid causes an error in the preformed creatinine determination, but does not affect the determination of total creatinine. On the basis of their experiments, they conclude that the difference between creatinine preformed and total creatinine does not represent creatine, since in their experiments with carbohydrate-free diets, they found no excretion of creatine.

It is obvious, therefore, that these two researches throw considerable doubt upon the value of the figures reported under the head of the preformed creatinine, but affect in no wise the values for the total creatinine. We may therefore without further reservation proceed to a consideration of the total creatinine-nitrogen as reported in table 29.

One of the most striking features of these results is their great regularity. After the first 2 days there was an almost continuous fall in the total creatinine-nitrogen from the maximum on the third day of 0.55 to a minimum on the last day of the fast of 0.32. The minor fluctuations from this regular fall are so few as to be negligible.

In the fasting experiments with S. A. B. at Wesleyan University, the almost absolute constancy in the total creatinine-nitrogen was a matter of special comment and in the report of the results it was pointed out that it was probably more than a mere coincidence that the sum of the creatine-nitrogen and the preformed creatinine-nitrogen remained constant each day as the fast progressed. It will be seen that for the first 7 days of the fast with L., while the results were not

[1]Greenwald, Journ. Biol. Chem., 1913, **14**, p. 87.
[2]Graham and Poulton, Proc. Royal Soc., ser. B., 1914, **87**, p. 205.

constant, nevertheless the amount excreted did not vary greatly, although the variation was wholly in the line of a decrease toward the end. It was only after the thirteenth day that any considerable decrease in the total creatinine-nitrogen appeared; from that time it remained at a lower level, gradually decreasing until the end of the fast, the lowest value being found on the last day of the fast.

Of particular interest is the striking regularity in the percentage of the total nitrogen excreted in the form of total creatinine. Omitting the first 2 days, the percentage ranged from 5.11 per cent on the sixth day to 4.17 per cent on the twenty-fourth day.

On the first 2 days of the fast, the values for preformed creatinine-nitrogen and for total creatinine-nitrogen are essentially the same, and it is only with the third day that we begin to find the measurable differences which have been ascribed to creatine. In an attempt to explain the presence of creatine in the fasting urine, two hypotheses have been presented: one, that as a result of inanition the body loses its power of converting creatine to creatinine before excreting it, and the other that creatine was representative of the flesh katabolized, as in the disappearance of the body material a certain amount of creatine normally existing in the flesh was liberated and excreted in the urine. Against the validity of this latter assumption was the obviously significant fact that the sum of the creatinine-nitrogen and the creatine-nitrogen remained constant. While without doubt the observations of Greenwald and of Graham and Poulton affect the quantitative value of the difference between preformed creatinine and total creatinine, the accumulative evidence of the past eight years is such as to make it reasonably certain that creatine is excreted unchanged in fasting and pathological urines and our uncertainty lies, therefore, only in our knowledge as to the quantities thus excreted.

In a recent paper Folin[1] has reiterated his belief regarding the interpretation of the creatinine output in the following terms: "The creatinine elimination becomes more clearly than ever the most clear-cut index or measure of the total normal tissue metabolism." In this paper Folin explains the appearance of creatine as an abnormal splitting off of a cleavage product which is normally excreted as creatinine and disclaims the presence of isolated, uncombined creatine in flesh, admitting that in fasting and in various pathological conditions the normal breaking down into creatinine is accompanied more or less by an abnormal breaking down into creatine. It is clear, therefore, that according to all of Folin's recent interpretations the exact quantitative knowledge regarding the creatine in urine has no longer the significance formerly attributed to it, and hence the criticisms of Greenwald and of Graham and Poulton, while admittedly justifiable so far as technique is concerned, apply to a determination which bids fair to have but

[1]Folin and Denis, Journ. Biol. Chem., 1914, 17, p. 501.

little physiological significance. The pathological significance must, however, be measurably increased in value as a result of their researches.

Of fundamental importance is the possibility of using Folin's interpretation of the total creatinine excretion as an index of the metabolism of normal tissue. Throughout this entire monograph stress has been laid upon the importance of knowing, if possible, the active mass of protoplasmic tissue in the body,[1] and the question arises, "Have we in the total creatinine excretion an interpretable index of the changes in the active mass of protoplasmic tissue?" If, as is pointed out in the section on energy transformation, the active mass of protoplasmic tissue is the fundamental factor in the determination of the total energy requirement, we should normally expect to find that the total energy output decreased with the loss of creatinine, indicating a continual decrease in the tissue metabolism. As a matter of fact, as the fast progresses, such a decrease in the total heat-production is clearly shown by various methods and yet, as a reference to the section on the pulse-rate will show, our whole conception of the relationship between creatinine and energy transformation is seriously affected by the increase in the pulse-rate found with this subject during the last week of the fast. The total energy transformation is clearly due to the active mass of protoplasmic tissue and the stimulus to cellular activity, but at no part of the fast were conditions so sharply differentiated that we may say with accuracy that the *loss* in the heat-production was directly comparable to the *loss* in the normal katabolized tissue, as indicated by the decrease in the total creatinine excretion. Similarly, we find no definite relationship between the creatinine excretion and the total basal heat production, utilizing the creatinine elimination as an index of the total mass of active protoplasmic tissue remaining in the body. It is, however, of great significance that the total creatinine excretion decreased regularly as the fast progressed, thus indicating not an approximation to depletion but a distinct tendency on the part of the body to a conservation of its active protoplasmic tissue.

The decreasing differences between the preformed creatinine and the total creatinine observable toward the end of the fast are not easily explained upon the ground of the influence of acetone bodies in the urine, since from the determinations of the ammonia and the β-oxybutyric acid we have no reason to believe that the acidosis was materially less in the last week than at any other time. These values would therefore indicate that a sufficient amount of acetone bodies was not present in these urines to affect materially the quantitative determinations of preformed creatinine.

[1]During the reading of this proof, we received the admirable article, "Basal Metabolism and Creatinine Elimination," by W. W. Palmer, J. H. Means, and J. L. Gamble (Journ. Biol. Chem., 1914, **19**, p. 239).

With the taking of food, there was a slight increase in the total creatinine-nitrogen on the first day, and the difference between the nitrogen of the creatinine preformed and of the total creatinine disappears after this day.

TABLE 30.—*Total creatinine excreted in urine, per day and per kilogram of body-weight, in experiment with L.*

Date.	Day of fast.	Creatinine excreted.	
		Per kilogram of body-weight per day.	Per day.
1912.		*gm.*	*mg.*
Apr. 14–15	1st	1.29	21.5
15–16	2d	1.23	20.8
16–17	3d	1.47	25.2
17–18	4th	1.45	25.3
18–19	5th	1.37	24.2
19–20	6th	1.40	24.9
20–21	7th	1.31	23.5
21–22	8th	1.35	24.4
22–23	9th	1.35	24.6
23–24	10th	1.31	24.1
24–25	11th	1.31	24.3
25–26	12th	1.31	24.4
26–27	13th	1.28	23.9
27–28	14th	1.19	22.3
28–29	15th	1.03	19.4
29–30	16th	1.14	21.7
Apr. 30–May 1	17th	1.07	20.6
May 1– 2	18th	1.09	21.1
2– 3	19th	1.03	20.1
3– 4	20th	1.01	19.8
4– 5	21st	1.01	19.9
5– 6	22d	.96	19.1
6– 7	23d	.98	19.6
7– 8	24th	.92	18.5
8– 9	25th	.94	19.0
9–10	26th	.96	19.5
10–11	27th	.95	19.4
11–12	28th	.91	18.7
12–13	29th	.94	19.5
13–14	30th	.89	18.6
14–15	31st	.86	18.1
15–16		1.00	21.2
16–17		.91	19.3
17–18		[1].88	18.5

[1]Determined in urine for about 22 hours.

As an indication of the relationship between the metabolism of active tissue and the body-weight—a relationship that must at best be somewhat approximate, depending in large part upon the composition of the body—it has been customary to obtain a so-called creatinine coefficient by dividing the total creatinine excretion each day by the body-weight. This coefficient is normally found to be not far from

20 to 30 milligrams. We have computed the creatinine coefficient for our subject L. for each day of the 31-day fast and give the values in table 30. After the first 2 days of fasting, the coefficient remains practically constant until the fourteenth day; it then shows a tendency to fall for a week, and the last 10 days it remains nearly constant at 19 milligrams.

Rest Nitrogen.

When the urea-nitrogen, the ammonia-nitrogen, the uric-acid nitrogen, and the total creatinine-nitrogen are combined, we find that the total amount is somewhat less than the total nitrogen found by th Kjeldahl method. This remainder, or the so-called "rest-nitrogen," amounts usually to not far from 0.5 gram of nitrogen in the observations with our subject L. The values for this undetermined nitrogen are recorded in table 29, in which it is seen that the largest amount (0.86 gram) was found on the fourth day and the smallest (0.17 gram) on the twenty-second day. Since these values include all the errors in the analyses, the amounts thus recorded are not unexpected. Usually they form about 5 per cent of the total nitrogen and in these records vary from 7.22 per cent on the fourth day of the fast to 2.18 per cent on the twenty-second day. In the food period following the fast, we find a large increase on the percentage basis in this rest nitrogen, which reaches 15.23 per cent of the total nitrogen excretion. It thus appears that the chief factor affecting the nitrogen excretion on the last day was the urea, for the absolute amounts of ammonia-nitrogen, uric-acid nitrogen, creatinine-nitrogen, and rest-nitrogen remained essentially constant on all three days of food.

ACID RADICLES.

Fasting urine contains a large number of acid radicles which may be either organic or inorganic. Thus there are always present considerable amounts of chlorine, phosphorus pentoxide, sulphur trioxide, and (particularly in fasting experiments) β-oxybutyric and other fatty acids. By using Folin's titration method, it has been possible to determine the "total acidity." For a clear understanding of the quantitative relationships of these various acid radicles, direct determinations were made of the total chlorine, phosphorus pentoxide, total sulphur, and β-oxybutyric acid.

Chlorine.

Owing to the general satisfaction with the standard Volhard method, chlorine has perhaps received more attention than any other of the inorganic constituents of the urine. Recognizing the importance of the determination of this constituent, especially in view of the emphasis laid upon the supposed excess storage of chlorine in the body under

normal conditions, we made duplicate determinations of the chlorine in the urine for each day of the fast. The chlorine excretion in fasting experiments has always had a particular interest, as the chlorine curve almost invariably follows a fairly regular course. It is furthermore important as presumably demonstrating whether or not the fast is a true one, for it is commonly supposed that unless the food surreptitiously taken is pure fat or pure carbohydrate, it is practically impossible for a subject to break his fast without almost immediately affecting the chlorine excretion. On the other hand, it was found,

TABLE 31.—*Chlorine* (Cl) *excreted in urine daily by fasting subjects.*

Day of fast.	L.	Succi.					Cetti.	Beauté.	Tosca.[1]	S. A. B.
		Florence.	Naples.[1]	Rome.	Vienna.[1]	Hamburg.[1]				
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Last food day	.....	[2]6.322	4.51	4.792	.....	.....	5.432	6.7	7.51	4.11
1st	3.77	1.350	4.65	3.908	9.03	.....	1.606	3.2	2.99	1.45
2d	1.02	.539	2.86	2.212	3.21	.....	2.303	2.0	1.73	1.34
3d	.79	1.155	2.00	1.799	1.55	.....	1.7	1.5	3.66	.62
4th	.59	.848	.47	1.198	1.48	.....	1.548	1.3	1.90	.25
5th	.41	.817	.55	1.092	1.18	.....	1.396	.....	.38	.....
6th	.40	.840	.38	1.044	1.29	.....	1.088	1.0	.30	.39
7th	.55	.800	.37	.973	1.11	.....	.95	.84	.32	.42
8th	.32	.736	.25	.700	1.12	.....	.814	.59	1.15	.....
9th	.31	.550	.44	.702	1.21	.....	1.104	.....	1.32	.....
10th	.28	.513	.47	.412	.87	.....	.62	.39	1.07	.....
11th	.36	.332	.64	.434	.92	.....	.....	.30	.98	.....
12th	.31	.405	.86	.567	.82	.....	.....	.18	1.29	.....
13th	.32	.230	.52	.532	.58	.....	.....	.....	.85	.....
14th	.26	.119	.50	.497	.55	.....	.....	.24	.68	.....
15th	.16	.137	.58	.436	.51	.....	.....	.....	.....	.....
16th	.14	.113	.47	.403	.45	.....	.....	.....	.....	.....
17th	.12	.130	.80	.322	.58	.....	.....	.....	.....	.....
18th	.15	.258	.67	.306	.44	.....	.....	.....	.....	.....
19th	.16	.298	.40	.217	.67	.....	.....	.....	.....	.....
20th	.15	.311	.71	.233	.42	.....	.....	.....	.....	.....
21st	.18	.234	.56	.....	.42	.....	.....	.....	.....	.....
22d	.21	.216	.....	.....	.....	.....	.....	.....	.....	.....
23d	.18	.219	.....	.....	.....	0.30	.....	.....	.....	.....
24th	.10	.235	.....	.....	.....	.29	.....	.....	.....	.....
25th	.18	.204	.....	.....	.....	.20	.....	.....	.....	.....
26th	.16	.118	.....	.....	.....	.21	.....	.....	.....	.....
27th	.16	.139	.....	.....	.....	.15	.....	.....	.....	.....
28th	.14	.239	.....	.....	.....	.19	.....	.....	.....	.....
29th	.12	.428	.....	.....	.....	.21	.....	.....	.....	.....
30th	.14	.688	.....	.....	.....	.33	.....	.....	.....	.....
31st	.13	.....	.....	.....	.....	.....	.....	.....	.....	.....
1st food day	.23	.....	.....	.....	.....	.....	.....	.....	.....	.....
2d food day	.26	.....	.....	.....	.....	.....	.....	.....	.....	.....
3d food day	[3].18	.....	.....	.....	.....	.....	.....	.....	.....	.....

[1]Reported by the investigators as NaCl, but converted to chlorine for purposes of comparison.
[2]Average of 6 days before fast began.
[3]Determined in the urine for about 22 hours.

in the experiment with L., that when the subject took considerable amounts of food on the 3 days following the fast, the excretion of chlorine was but slightly affected, certainly not enough to be considered as proof that food had been taken. The character of the diet on these food days easily explains this absence of influence upon the excretion of chlorine.

The determinations of the chlorine excretion were made under Dr. Peters's supervision by Mr. W. F. O'Hara according to the Volhard method, the excess of silver nitrate added being determined in a filtered portion of the urine. These values are compared in table 31 with the values obtained for several other subjects in long fasting experiments.

With L. there was a large excretion of chlorine on the first day of the fast, doubtless from the food previously taken. This was followed by a marked fall, even on the second day, this decrease continuing almost regularly until the fifteenth day, when the excretion reached a new minimum level. It subsequently fluctuated slightly until the end of the fast. On the 3 food days there was a slight increase over the latter part of the fasting period.

An intelligent comparison of the values found for L. with those found for other fasting subjects is somewhat difficult, owing to the facts that frequently the basis upon which the chlorine is reported is somewhat obscure and that some of the subjects, Succi in particular, were accustomed to drink water containing more or less chlorine. Apparently the chlorine excretion in complete inanition varies widely with different individuals, for it will be seen at once, by inspection of the values in table 31, that the excretion found for L., particularly in the first part of the fast, was lower than that found for any other subject except for a few days with Succi[1] in the Naples fast, for 3 days with Tosca, and for 4 days with S. A. B. In the latter part of the long fasts, however, there is more of a tendency toward uniformity, although the values for Succi at Naples and at Vienna, and those for the latter portion of Tosca's fast, are much higher than those found with L. There is a general tendency shown with all of the subjects for the excretion to decrease gradually until the fifteenth day, but not so rapidly as was found for our subject. The observations of Brugsch on Succi at Hamburg give values that agree well with those found for L.

Relationship between chlorine excretion and preformed water lost.—A critical examination of the tables in the report of the earlier fasting experiments[2] shows a rather interesting relationship between the excretion of chlorine and the loss of preformed water from the body. For a long time we have been at a loss to explain the marked variations in the absolute amounts of chlorine excreted on different days of a fast

[1]I have been unable to obtain the original chlorine data in the study made of Succi's urine by Korányi, published in Orvosi hetilap, 1894, Nos. 39–40. See autoreferat, Maly, Jahrb. d. Tier-Chemie, 1894, 24, p. 268. Korányi also studied the depression of the freezing-point.

[2]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, table 216, page 415, and table 229, page 469.

by different subjects, there being almost no uniformity; some subjects, as Tosca, Cetti, and Succi in Vienna, excreting much larger amounts than others. In a relatively few fasting experiments, both the loss of preformed water from the body and the chlorine excretion have been determined, thus supplying data which permit comparison. Such a comparison is made in table 32, which gives the amount of water taken,

TABLE 32.—*Preformed water eliminated from the body and accompanying excretion of chlorine (Cl) in experiments with fasting subjects.*

Subject.	Day of fast.	Water consumed. A	Chlorine (Cl) in urine. B	Preformed water lost.[1] Total.[1] C	Preformed water lost.[1] Per gram of chlorine. (C÷B) D	Water in urine. Total. E	Water in urine. Per gram of chlorine. (E÷B) F
		gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
L.....	1st....	720	3.77	585	155	630.2	167
	2d.....	750	1.02	448	439	436.6	428
	3d.....	750	.79	350	443	530.6	672
	4th....	750	.59	225	381	674.4	1143
S. A. B., Exp. 73...	1st....	2082	1.63	377	231	2225.8	1366
	2d.....	2747	.47	341	726	2928.2	6230
Exp. 75...	1st....	1973	1.45	−334	−230	1469.6	1014
	2d.....	1729	1.34	273	204	1839.9	1373
Exp. 77...	1st....	2048	5.29	736	139	2528.2	478
	2d.....	1593	1.67	713	427	2122.9	1271
H. E. S., Exp. 79...	1st....	783	2.92	471	161	996.1	341
	2d.....	340	3.62	623	172	810.0	224
C. R. Y., Exp. 80...	1st....	133	8.90	1500	169	1105.8	124
	2d.....	206	4.03	1132	281	734.8	182
A. H. M., Exp. 81..	1st....	291	3.88	540	139	621.3	160
	2d.....	194	2.79	777	278	783.2	281
H. C. K., Exp. 82 ..	1st....	858	3.45	47	14	538.6	156
	2d.....	1093	6.71	991	148	1740.1	259
H. R. D., Exp. 83..	1st....	1467	.52	−142	−273	1159.2	2229
	2d.....	884	.63	286	454	1012.4	1607
N. M. P., Exp. 85..	1st....	705	4.58	744	162	1145.1	250
	2d.....	708	1.46	231	158	642.4	440
D. W., Exp. 89....	1st....	115	5.86	822	140	599.6	102
	2d.....	357	1.81	356	197	492.2	272

[1]Preformed water other than that resulting from the disintegration of flesh and fat. (Column J, table 62, and Carnegie Institution of Washington Pub. 77, table 229, column c). Since the chlorine in flesh is not a large proportion of the total chlorine, the water of flesh and fat is purposely omitted in this discussion.

the chlorine excreted in the urine, the preformed water lost from or stored in the body,[1] the preformed water lost per gram of chlorine excreted, the water in the urine, and the water in the urine per gram of chlorine excreted during fasting. These factors are given not only for the first 4 days of the experiment with L., but also for the first 2 days for

[1]For discussion of this factor, see page 408.

a number of short fasting experiments made with eight subjects at Wesleyan University.

It is conceivable that variations in the chlorine excretion might be due, in part at least, to a flushing out of the body, and hence we should expect to find the chlorine excretion varying to a certain degree with the variations in the volume of urine or of the water taken. An examination of the figures in the last column of table 32 (column F) shows, however, that the water in the urine per gram of chlorine excreted undergoes wide variations, ranging from 102 grams to 6,230 grams, with no obvious average value.

If we consider the body as losing regularly not only carbohydrate, fat, and protein from its original store of substance at the beginning of the fast, but also losing regular amounts of preformed water, *i. e.*, water of flesh and fatty tissue (see note to table 32), and water existing in the fluids of the body, we can see that the importance of the determination of the preformed water lost is much greater than would at first appear. The values for the preformed water lost by these fasting subjects are given in column C of table 32, and for the preformed water lost per gram of chlorine in column D. An examination of the values for the preformed water lost per gram of chlorine shows that there is at least a semblance to regularity. This is more clearly seen if the first day of the experiment is omitted, as may properly be done, since it is natural to suppose that the chlorine excretion on the first day may have been influenced by the previous diet. Excluding the values for the first day, then, we find that the remaining values range from 726 on the second day of experiment 73 with S. A. B. to as low as 148 on the second day of experiment 82 with H. C. K. Aside from the very high value found in experiment 73, it will be seen that there is a fairly close agreement between the chlorine excreted and the preformed water lost from the body. It would thus appear that, in the discharge of this water, there is excreted simultaneously an amount of chlorine approximately proportional to the total preformed water lost. It is obvious that all of the factors involved in the determination of the preformed water lost from the body are such as to make the absolute values of some of the determinations problematical, and yet we believe that as a whole there is sufficient agreement here to indicate some approximate relationship between the chlorine and the preformed water lost from the body.

Source of chlorine excreted.—The exact source of the chlorine excreted in the first days of fasting is by no means certain, but it is clear that the small amounts excreted, in the urine after the first few days of fasting, correspond to the usual percentage of chlorine commonly considered as belonging to human flesh. Thus Katz,[1] whose analyses have been considered as remarkably accurate, maintains that human

[1]Katz, Archiv f. d. ges. Physiol., 1896, 63, p. 1.

muscle contains 0.07 per cent chlorine. Furthermore, Magnus-Levy's[1] analysis of the flesh of a suicide agrees remarkably well with the values of Katz. If we use this factor 0.07 for computing the chlorine in the flesh katabolized by the subject L. as recorded in column Q, table 61 (page 403), the values found would be approximately the amounts of chlorine actually excreted. For instance, on the twenty-fifth day, there were 235 grams of flesh katabolized, the excretion of chlorine being somewhat larger than the average for this part of the fast. Applying the factor of Katz, we find that 0.07 per cent of 235 grams would give 0.165 gram of chlorine, while the amount actually excreted on that day as shown by analysis was 0.18 gram. It is clear, therefore, that, at least in the later stages of inanition, chlorine is derived for the most part from disintegrated muscle substance. The large storage of salt in the skin, which was noted by Wahlgren[2] and subsequently further studied by Padtberg,[3] and Scholz and Hinkel,[4] must therefore have been rapidly depleted during the first days of the fast. In any event, the total amount of chlorine involved throughout the whole 31 days of our fasting experiment was but 12.27 grams, an amount so small as to cast a doubt upon the theory that there is an excess[5] of chlorine stored in the body.

Phosphorus.

Since phosphorus has so intimate a relationship with both the mineral and the organic constituents of the body, observations have been made of the amounts present in the fasting urine of a large number of subjects. The phosphorus in the urine of L. was determined by Mr. W. F. O'Hara under the supervision of Dr. Peters, for each day of the fast and for the following food days, by titration with uranium acetate. Usage is followed here in expressing the values as phosphorus pentoxide instead of as phosphorus, although the inconsistency of expressing the elements in terms of their compounds is obvious. The absolute amounts of phosphorus pentoxide determined in these urines, together with those found in other long fasting experiments, are given in table 33.

The values obtained for L. show an increasing amount for the first 4 days and thereafter a very regular decrease for the remainder of the fast. The maximum amount, 2.90 grams of phosphorus pentoxide, was observed on the fourth day and the minimum amount, 1.32 grams, on the last day. While in the first part of the fast the values for L. are exceeded by those for Cetti and Beauté and approximately equaled by those for S. A. B., in the latter part of the fast they are measurably

[1]Magnus-Levy, Biochem. Zeitschr., 1910, **24**, p. 363.
[2]Wahlgren, Archiv f. exp. Path. u. Pharm., 1909, **61**, p. 97.
[3]Padtberg, Archiv f. exp. Path. u. Pharm., 1910, **63**, p. 60.
[4]Scholz and Hinkel, Deutsch. Archiv f. klin. Med., 1913, **112**, p. 334.
[5]For a discussion of this point, see Magnus-Levy, Physiologie des Stoffwechsels, von Noorden's Handbuch der Path. des Stoffwechsels, Berlin, 1906, **1**, p. 451; Munk, Archiv f. Path. Anat. u. Physiol., 1893, Supp. **131**, p. 146; and Morawitz, Oppenheimer's Handbuch der Biochemie, Jena, 1910, **4** (2), p. 282.

higher than those recorded for any other subject. The only other fast in which the phosphorus was determined, and which extended over so long a period as that for our subject, was Succi's fast in Florence, but the amount excreted by this subject was considerably less than that found for L. The values obtained by Brugsch on Succi in the

TABLE 33.—*Phosphorus* (P_2O_5) *eliminated in urine daily by fasting subjects.*

Day of fast.	L.	Succi.					Cetti.	Beauté.	Tosca.	S. A. B.
		Florence.	Naples.	Rome.	Vienna.	Hamburg.				
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Last food day	.....	.....	1.90	1.792	.....	.....	2.76	4.14	2.670	2.318
1st	1.66	1.930	1.78	2.499	2.98	.....	2.597	2.26	1.550	1.431
2d	2.48	2.051	1.82	1.559	2.75	.....	2.925	2.93	1.830	2.255
3d	2.51	2.090	1.95	1.528	2.52	.....	3.289	2.98	2 654	2.055
4th	2.90	2.120	1.46	1.662	2.54	.....	2.974	2.91	2.934	2.406
5th	2.64	2.394	2 64	2.100	2.51	.....	2.871	.....	1.749	2.078
6th	2.33	2.150	2.47	1.561	2.27	.....	2.667	2.37	1.069	2.071
7th	1.84	1.865	2.32	1.678	2.13	.....	2.663	1.84	.713	2.081
8th	1.84	1.601	1.48	1.158	2.31	.....	1.722	1.89	1.658	.....
9th	2.13	1.360	1.49	.841	2.40	.....	2.065	.....	1.702	.....
10th	1.97	1.246	1.23	.662	1.68	.....	.948	1.60	1.461	.....
11th	1.95	1.420	1.22	.518	1.41	.....	.....	1.54	1.097	.....
12th	1.70	1.012	1.98	.769	1.35	.....	.....	1.55	1.312	.....
13th	1.95	.363	1.11	.879	1.04	.....	.....	.....	1.114	.....
14th	1.86	.996	1.14	.428	.99	.....	.....	1.25	.869	.....
15th	1.47	1.029	1.33	.....	1.32	.....	.....	.....	.....	.....
16th	2.04	1.077	1.50	.465	.876	.....	.....	.....	.....	.....
17th	1.99	1.218	1.02	1.162	1.34	.....	.....	.....	.....	.....
18th	1.86	1.005	1.36	1.079	.86	.....	.....	.....	.....	.....
19th	1.75	.953	1.02	.725	1.14	.....	.....	.....	.....	.....
20th	1.47	.875	1.19	.610	.67	.....	.....	.....	.....	.....
21st	1.60	.747	1.11	.....	.64	.....	.....	.....	.....	.....
22d	1.57	.718	.....	.....	.....	.....	.....	.....	.....	.....
23d	1.62	1.049	.....	.....	.....	0.96	.....	.....	.....	.....
24th	1.55	.790	.....	.....	.....	1.062	.....	.....	.....	.....
25th	1.53	.592	.....	.....	.....	.980	.....	.....	.....	.....
26th	1.49	.783	.....	.....	.....	.900	.....	.....	.....	.....
27th	1.41	.861	.....	.....	.....	1.056	.....	.....	.....	.....
28th	1.35	.945	.....	.....	.....	.901	.....	.....	.....	.....
29th	1.46	.789	.....	.....	.....	.754	.....	.....	.....	.....
30th	1.39	1.019	.....	.....	.....	1.545	.....	.....	.....	.....
31st	1.32	.....	.....	.....	.....	.....	.....	.....	.....	.....
1st food day	.74	.....	.....	.....	.....	.....	.....	.....	.....	.....
2d food day	.31	.....	.....	.....	.....	.....	.....	.....	.....	.....
3d food day	*.21	.....	.....	.....	.....	.....	.....	.....	.....	.....

*Determined in urine for about 22 hours.

Hamburg fast are also measurably less than those reported for our fasting subject.

Relationship between phosphorus and total nitrogen.—Owing to the intimate relationship between phosphorus and the organic tissues of the body, particularly muscle, the ratio between phosphorus and total

nitrogen has frequently been computed for fasting experiments. The well-known determinations of phosphorus pentoxide and nitrogen in muscle show that for each gram of phosphorus pentoxide there should be 6.6 grams of nitrogen. The ratios between nitrogen and phosphorus pentoxide have been computed, not only for the fasting experiment with L., but likewise, in so far as the data permit, for those of

TABLE 34.—*Ratio of nitrogen to phosphorus* $\left(\frac{N}{P_2O_5}\right)$ *in urine of fasting subjects.*

Day of fast.	L.	Succi.				Cetti.	Beauté.	Tosca.	S. A. B.
		Florence.	Rome.	Vienna.	Hamburg.				
Last food day	.....	.....	5.10	.....	.....	4.89	3.97	5.24	8.41
1st	4.28	*7.87	3.57	5.70	.....	5.22	4.65	5.65	8.55
2d	3.39	5.91	5.88	4.07	.....	4.30	4.90	4.58	5.52
3d	4.52	7.30	5.68	4.19	.....	3.99	4.60	4.04	6.34
4th	4.09	6.64	5.09	4.25	.....	4.17	4.71	3.20	4.83
5th	3.94	5.90	4.77	4.46	.....	3.73	.....	4.50	5.23
6th	4.37	5.18	6.03	4.85	.....	3.79	4.54	7.23	5.19
7th	5.32	5.53	5.11	4.13	.....	4.09	5.25	8.57	4.87
8th	5.58	5.85	7.03	4.22	.....	5.17	5.03	4.64	.....
9th	5.04	6.29	7.55	4.19	.....	5.24	.....	4.32	.....
10th	5.10	5.96	8.63	4.24	.....	10.00	5.23	4.65	.....
11th	5.26	6.11	9.54	4.48	.....	.....	5.51	5.60	.....
12th	5.96	7.79	6.65	5.07	.....	.....	5.65	5.31	.....
13th	5.31	10.63	5.44	4.94	.....	.....	.....	5.04	.....
14th	5.61	5.89	10.30	4.71	.....	.....	6.22	4.70	.....
15th	5.76	5.50	.....	3.83	.....	.....	.....	.....	.....
16th	4.70	5.62	6.77	4.83	.....	.....	.....	.....	.....
17th	4.43	5.57	2.86	4.03	.....	.....	.....	.....	.....
18th	4.45	5.97	3.76	4.19	.....	.....	.....	.....	.....
19th	4.78	5.81	5.27	5.00	.....	.....	.....	.....	.....
20th	5.23	5.51	5.66	4.93	.....	.....	.....	.....	.....
21st	4.96	5.72	.....	4.41	.....	.....	.....	.....	.....
22d	4.94	4.90	.....	.....	.....	.....	.....	.....	.....
23d	4.51	4.99	.....	.....	6.08	.....	.....	.....	.....
24th	5.26	7.73	.....	.....	6.04	.....	.....	.....	.....
25th	5.10	11.23	.....	.....	6.40	.....	.....	.....	.....
26th	5.29	7.11	.....	.....	6.87	.....	.....	.....	.....
27th	5.72	6.85	.....	.....	5.97	.....	.....	.....	.....
28th	5.64	6.52	.....	.....	4.93	.....	.....	.....	.....
29th	5.16	5.69	.....	.....	5.56	.....	.....	.....	.....
30th	5.63	7.14	.....	.....	5.45	.....	.....	.....	.....
31st	5.26	.....	.....	.....	.....	.....	.....	.....	.....
1st food day	6.53	.....	.....	.....	.....	.....	.....	.....	.....
2d food day	12.29	.....	.....	.....	.....	.....	.....	.....	.....
3d food day	13.10	.....	.....	.....	.....	.....	.....	.....	.....

*The ratios shown in this column have been obtained by means of the nitrogen as corrected by Munk. (See table 26, p. 249.)

the earlier fasting experiments reported in table 33. These ratios are given in table 34.

Considering the fasting values for L., we find that in no case do they reach the theoretical relationship found with muscle, namely, 6.6. The highest value was 5.96 on the twelfth day and the lowest value was

3.39 on the second day of the fast. Furthermore, the figures show no definite increment in the ratio as the fast progressed. While it is true that values less than 5 are not found on the last 8 days of the fast, nevertheless there is a period—that between the seventh and the fifteenth days—when the values again all lie above 5, while between the fifteenth and the twenty-fourth days values as low as 4.4 are found.

In examining the values for the other fasts, we find several which show distinctly abnormal values for the first day, *i. e.*, 7.87 for the first day of Succi's Florence fast, and 8.55 for the first day of the fast of S. A. B., but this would naturally be expected. On the other hand, after the first day the values should lie well below 6.6 and any above this are open to suspicion. The ratios established by the Freunds for the Vienna fast of Succi are remarkably constant, as are those of Brugsch for a later fast of Succi in Hamburg. Perhaps the greatest uniformity in ratios is shown by Cathcart's subject Beauté, these ratios gradually and steadily increasing as the fast progressed. The values for Succi in the Florence fast are somewhat vitiated by the uncertainty in the nitrogen determinations, although the values were computed on the basis of nitrogen as corrected by Munk.

Source of phosphorus excreted.—Comparing these ratios, particularly those for L., with the theoretical relationship with flesh, we find in all of the experiments a tendency toward a much larger excretion of phosphorus pentoxide in its relation to nitrogen than occurs in the ordinary composition of flesh. The possible sources of phosphorus in the body other than the flesh are of course the nucleins and, above all, the mineral matter of the bony structure. It is now the consensus of opinion that the disturbance in the relationship between the phosphorus pentoxide and nitrogen in fasting experiments is due exclusively to the material draft upon the bony structure as the fast progresses.[1] This was clearly set forth by Munk in his discussion of the experiments with Cetti and Breithaupt, but as these were short experiments Munk frankly stated that he expected to find that the ratio would become smaller and smaller as the fast progressed. The ratios in the 31-day fast with L. do not, however, become smaller as the fast continued, but on the other hand tend to become higher in the last week than at any other time. Brugsch has already commented upon the very high values found in the last week of his study with Succi.

During the fast with L., 277.32 grams of nitrogen[2] were excreted, corresponding to 8,319.6 grams of flesh katabolized. If we assume that this flesh had normally combined with it 0.5 per cent of phosphorus pentoxide, the total amount combined with the katabolized flesh would be equal to 41.6 grams. Since 56.63 grams of phosphorus

[1]Wellman (Archiv f. d. ges. Physiol., 1907–1908, **121**, p. 508) believes that the calcium and phosphorus losses found by him conform with Munk's conclusion that there is considerable loss of calcium and phosphorus from the bones during starvation.

[2]This amount does not include the nitrogen excreted through the skin (see table 22).

pentoxide were excreted during the fast, it will be seen that there was distinctly an excess excretion, amounting to 15 grams of phosphorus pentoxide for the whole fast. This was undoubtedly derived—in large part, at least—from the bones. It was hoped that the present-day technique of Roentgen photography would show any material attacks upon the bony structure and possible depletion of calcium, but the excellent series of X-ray photographs taken by Dr. Francis H. Williams, of the Boston City Hospital, did not indicate this. On the other hand, when one considers the large storage of calcium in the body and the relatively small draft, an ocular indication of such a draft which could be measured could hardly be expected.

The exact apportionment of the phosphorus pentoxide between muscle and bone is not permissible with the experimental data at present in our hands. In all probability the amount of phosphorus pentoxide actually drawn from the skeleton was considerably more than 15 grams.

Since after the first few days there was no material increase in the uric-acid excretion as the fast progressed, there was doubtless no direct attack upon the nucleins, and thus the increase in the phosphorus pentoxide could not have been derived from that source.

Sulphur.

Sulphur as an integral component of protoplasm is oxidized and excreted in the urine in several forms: first, as sulphates; second, in the form of conjugated sulphates, or sulphuric acid combined with organic radicles; and finally, as so-called neutral or unoxidized sulphur. The apportionment of the total sulphur output among these various components has been studied during fasting in considerable detail, both in the laboratory of Wesleyan University and by Cathcart. In the series of experiments carried out on L., it was impossible to separate the sulphur, owing to the lack of experimental material, and only the total sulphur was determined. These determinations were personally made by Dr. A. W. Peters, the constancy in the results testifying to his technical skill.

It has been the custom of many writers to report the sulphur excretion as sulphuric acid or sulphur trioxide, but the values given for L. in table 35 represent the daily excretion of total sulphur. For comparison, the sulphur excretion has been computed from the results given by other observers for fasting subjects, and these values are included in the table. Two difficulties arise in comparing our results with those obtained with other subjects. In the first place, frequently only the total sulphuric acid was determined and the organic sulphur was not included. Secondly (in the case of Succi, at least), the subject often drank mineral water containing measurable amounts of sulphates.

With our subject L., the sulphur excretion followed a course not unlike that of the nitrogen excretion, there being a slightly increasing amount excreted for the first 3 days and thereafter an almost continuous decrease until the end of the fast. The maximum amount (0.68 gram)

TABLE 35.—*Total sulphur* (S) *excreted in urine daily by fasting subjects.*

Day of fast.	L.	Succi.				Cetti.	Beauté.	S.A.B.
		Florence.	Naples.	Rome.	Vienna.			
	gm.	*gm.*[1]	*gm.*[2]	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Last food day..	....	....	1.04	0.532	....	....	1.33	1.36
1st.....	0.46	0.75	.76	.590	1.28	0.990	.614	.62
2d.....	.61	.72	.48	.277	.59	....	.934	.67
3d.....	.68	.75	.72	.346	.52	.925	.801	.75
4th.....	.67	.71	.60	.249	.64	....	.856	.72
5th.....	.65	.68	.58	.312	....	.711	....	.67
6th.....	.65	.59	.40	.187	.56	....	.712	.66
7th.....	.62	.55	.49	.276	.56	.781	.644	.62
8th.....	.64	.49	.48	.258	.46	....	.615	...
9th.....	.66	.43	.44	....	....	.831	....	...
10th.....	.61	.42	.58	.272	....	.619	.556	...
11th.....	.62	.45	.30	.....	.32	....	.570	...
12th.....	.62	.43	.79	.....	.38	....	.577	...
13th.....	.62	.30	.38	.....	....	....	....	...
14th.....	.60	.33	.29	.120	....	....	.536	...
15th.....	.50	.28	.20	.130	....	....	....	...
16th.....	.59	.26	.31	.....	.29	....	....	...
17th.....	.53	.32	.70	.251	.36	....	....	...
18th.....	.54	.21	.66	.207	....	....	....	...
19th.....	.55	.22	.35	.117	....	....	....	...
20th.....	.51	.24	.46	.....	.23	....	....	...
21st.....	.51	.21	.51	.....	....	....	....	...
22d.....	.50	.19	....	.....	....	....	....	...
23d.....	.51	.29	....	.....	....	....	....	...
24th.....	.49	.35	....	.....	....	....	....	...
25th.....	.49	.28	....	.....	....	....	....	...
26th.....	.54	.19	....	.....	....	....	....	...
27th.....	.52	.17	....	.....	....	....	....	...
28th.....	.53	.19	....	.....	....	....	....	...
29th.....	.52	.14	....	.....	....	....	....	...
30th.....	.52	.24	....	.....	....	....	....	...
31st.....	.49	....	....	.....	....	....	....	...
1st food day...	.39	....	....	.....	....	....	....	...
2d food day....	.22	....	....	.....	....	....	....	...
3d food day....	[3].36	....	....	.....	....	....	....	...

[1]Probably inorganic and ethereal. Given by the investigator as H_2SO_4, but converted to S for purposes of comparison.

[2]Probably inorganic and ethereal.

[3]Determined in urine for about 22 hours.

was excreted on the third day of the fast, and the minimum amount (0.49 gram) was found on the twenty-fourth, twenty-fifth, and thirty-first days.

The most carefully determined results for the other subjects are undoubtedly those for Cathcart's subject Beauté. Here again we find a decrease in the sulphur excretion as the fast progresses, the values for

the entire fast being not unlike those found for L. This is likewise true for the results of the observations on S. A. B.

Relationship between total nitrogen and total sulphur.—The total sulphur excretion has a special significance in that it is so intimately combined with the protoplasm that it is frequently suggested as an index of the total muscle katabolized. Since there is a relatively constant relation between the nitrogen and sulphur in muscle, *i. e.*,

TABLE 36.—*Ratio of nitrogen to total sulphur* $\left(\frac{N}{S}\right)$ *in urine of fasting subjects.*

Day of fast.	L.	Succi at Vienna.	Cetti.	Beauté.	S. A. B.
Last food day....	....	....	....	12.2	14.3
1st.....	15.4	13.3	13.7	17.1	19.6
2d.....	13.8	19.0	....	15.3	18.6
3d.....	16.7	20.3	14.2	17.1	17.4
4th.....	17.7	16.9	....	16.0	16.1
5th.....	16.0	....	15.1	....	16.3
6th.....	15.7	19.7	....	15.1	16.3
7th.....	15.8	15.7	13.9	15.0	16.3
8th.....	16.0	21.2	....	15.4	....
9th.....	16.3	....	13.0	....	....
10th.....	16.5	....	15.3	15.0	....
11th.....	16.5	19.7	....	14.9	....
12th.....	16.3	18.0	....	15.2	....
13th.....	16.7	....	....	...	....
14th.....	17.4	....	....	14.5	....
15th.....	16.9	....	....	....	....
16th.....	16.2	14.6	....	....	....
17th.....	16.6	15.0	....	....	....
18th.....	15.3	....	....	....	....
19th.....	15.2	....	....	....	....
20th.....	15.1	14.3	....	....	....
21st.....	15.5	....	....	....	....
22d.....	15.5	....	....	....	....
23d.....	14.3	....	....	....	....
24th.....	16.6	....	....	....	....
25th.....	15.9	....	....	....	....
26th.....	14.6	....	....	....	....
27th.....	15.5	....	....	....	....
28th.....	14.4	....	....	....	....
29th.....	14.5	....	....	....	....
30th.....	15.1	....	....	....	....
31st.....	14.2	....	....	....	....
1st food day.....	12.4	....	....	....	....
2d food day.....	17.3	....	....	....	....
3d food day.....	7.6	....	....	....	....

about 13.3 grams to 1 gram of sulphur, the relationship between the excretions of total nitrogen and total sulphur is worthy of note. The nitrogen-sulphur ratio has been computed not only for the subject L., but for a number of the other fasting subjects; these computed ratios are given in table 36. But one ratio for Succi is included in this table, that for the Vienna fast, in which the observations were made by the Freunds, for while it was permissible to include the observations of the

sulphur excretion in the other fasts in table 35, it was not permissible to compute the ratio between the nitrogen and the sulphur, since there were undoubtedly errors in the nitrogen determinations and probably likewise in those for the sulphur excretion.

The ratios found for L. show at first a slight increase, rising on the fourth day to a maximum of 17.7. They then decrease with considerable regularity, the lowest value, 14.2, being on the last day of the fast. In general, the ratios remain within very narrow limits. These values are again not unlike those found by Cathcart with Beauté, which showed a tendency to decrease as the fast progressed. The same tendency is shown by the values for S. A. B., although at no time during the 7-day fasting experiment did the ratio fall below 16.1.

All of the values found for L. show a somewhat higher excretion of nitrogen than would normally accompany the amount of sulphur excreted; it would appear, therefore, that there was a disintegration of sulphur-poor and nitrogen-rich substance other than muscle. Throughout all of the observations, it has been noted that on certain days there was always a marked lowering in the excretion of the urinary components. This lowering may be due either to an actual decrease in the katabolism on that day or to a possible loss of urine. The handling, sampling, and preservation of the urine were so strictly controlled that it would seem impossible for such a loss to occur. It is conceivable, of course, that the subject may not have emptied the bladder completely in the morning, but a compensating increase in the urine of the next day would then be expected, which was not observed. If we examine the values for sulphur, total creatinine, nitrogen, chlorine, and phosphorus, we find that there was a distinct lowering in the amount excreted on the fifteenth day of the fast, with occasionally a slight indication of a compensating increase on the sixteenth day. This points toward a loss of urine which we are as yet unable to account for. As a matter of fact, no disturbance in the nitrogen-sulphur ratio was found on the fifteenth day and, indeed, such disturbance was not expected.

On the other hand, we note a very definite increase in the sulphur-nitrogen ratio from 14.3 on the twenty-third day to 16.6 on the twenty-fourth day. An examination of the values for the total nitrogen excretion shows that here also there was a marked increase, thus indicating the disintegration of a nitrogen-rich and a sulphur-poor substance other than muscle. The general course of the values for sulphur and total creatinine show a striking similarity, indicating that the katabolism resulting in the excretion of total creatinine is accompanied by an excretion of sulphur. If we are to accept Folin's view that the total creatinine is an admirable index of the total katabolism of tissue, we may then conversely state that the sulphur is likewise an index.

TOTAL ACIDITY.

When the conditions are such that acidosis may be expected to develop, as in fasting, a determination of the total acidity of the urine is of special value. Accordingly the total acidity of the urine in this experiment was determined for each day of the fasting period and also for the 3 days following when food was taken. Under the direction of Dr. A. W. Peters, the determinations were made by W. F. O'Hara, according to the method of Folin,[1] in which potassium oxalate was used and the titration was carried out with 25 c.c. of urine. The values are given in table 37, expressed in terms of cubic centimeters of deci-normal sodium hydroxide solution.

TABLE 37.—*Total acidity* $\left(\frac{n}{10}NaOH\right)$ *of urine of fasting subjects.*

Day of fast.	L.	Beauté.	Day of fast.	L.	Succi at Hamburg.
	c.c.	c.c.		c.c.	c.c.
Last food day..	[1]409	582	18th.....	383	...
1st.....	285	378	19th.....	347	...
2d.....	499	640	20th.....	264	...
3d.....	558	687	21st.....	296	...
4th.....	655	604	22d.....	301	...
5th.....	570	...	23d.....	287	[2]384
6th.....	467	454	24th.....	328	295
7th.....	337	358	25th.....	303	263
8th.....	399	344	26th.....	289	300
9th.....	415	...	27th.....	284	283
10th.....	376	280	28th.....	253	265
11th.....	365	256	29th.....	268	156
12th.....	297	212	30th.....	263	103
13th.....	362	...	31st.....	227	...
14th.....	332	228	1st food day..	139	...
15th.....	313	...	2d food day..	56	...
16th.....	505	...	3d food day..	[3]59	...
17th.....	485	...			

[1]Acidity of urine on third food day before the fast.

[2]The figures in this column were reported by the investigator as normal sulphuric acid, but are here proportionately increased for purposes of comparison.

[3]Determined on urine for 22 hours.

At the beginning of the fast, the acidity increased rapidly until the maximum of 655 c.c. was reached on the fourth day. It then showed a general tendency to decrease as the fast progressed, although occasionally unusually high values were found, as on the sixteenth and seventeenth days of the fast. In the 3 food days following the fast, the acidity dropped almost immediately to about 60 c.c.

The fasting values best suited for comparison with the values for acidity found for L. are those determined by Cathcart on Beauté and by Brugsch on Succi in Hamburg. Cathcart's figures for the total acidity in the 14-day fast of Beauté show values ranging from a maxi-

[1]Folin, Am. Journ. Physiol., 1903, **9**, p. 265.

mum of 687 on the third day of the fast to a minimum of 212 on the twelfth day of the fast. Following the fasting period the subject was given a starch-cream diet, and the acidity immediately dropped to approximately 100 c.c.

From the twenty-third to the thirtieth days of the fast in Hamburg, Brugsch found with Succi values ranging from 384 c.c. on the twenty-third day to 103 c.c. on the thirtieth day—values which are not incomparable with those found by us with L.

It was impossible, owing to the insufficient supply of urine, to determine the mineral acidity in the urine of our subject.

β-OXYBUTYRIC ACID.

In the earlier fasting experiments at Wesleyan University, there was strong evidence that a nitrogen-poor, carbon-rich substance was present in the urine in large amounts. This was shown by determinations of the carbon in the urine and the relationship between the carbon and nitrogen and calories. At that time the opinion was expressed that in all probability the material was β-oxybutyric acid, but we were then unable to make the determinations in addition to the other analyses. Special effort was therefore made in this fasting experiment to determine the β-oxybutyric acid in the urine as accurately as possible, although the interesting paper of Brugsch, reporting the Hamburg fast with Succi, and more recently the paper by Grafe,[1] have left no doubt as to the nature of this excess non-nitrogenous material in the urine of a fasting man.

Results of determinations.—Of the methods for the determination of β-oxybutyric acid which were available at the time of this experiment, that of Black[2] was best fitted for our purpose. By this method, plaster of paris is first mixed with the acidulated, dried urine and the mixture is then extracted with ether, the β-oxybutyric acid removed being determined with the polariscope.[3] The determinations were carried out by Miss Alice Johnson under the supervision of Dr. A. W. Peters.

Since these determinations were made, a large amount of research on β-oxybutyric acid has been carried out; in the light of the technique existing at the time of the experiment, however, the determinations, while admittedly having a relatively large error, are nevertheless sufficiently accurate to indicate that there was a material excretion of β-oxybutyric acid throughout the fast. The results are recorded in table 38 (column F).

On the second day of the fast only 0.5 gram of β-oxybutyric acid was found; this was wholly in line with what would be expected. Subsequently no values less than 1.4 grams were found until the fast had been

[1]Grafe, Zeitschr. f. physiol. Chemie, 1910, **65**, p. 21.
[2]Black, Journ. Biol. Chem., 1908, **5**, p. 207.
[3]For a more explicit statement of this procedure, see Benedict and Joslin, Carnegie Inst. Wash. Pub. 136, 1910, p. 25.

concluded. On the first day with food, the β-oxybutyric acid dropped at once to 0.8 gram. During the last week of the fast, the results obtained by the optical method showed a considerable amount of β-oxybutyric acid present in the urine.

TABLE 38.—*β-oxybutyric acid excreted in urine in experiment with L.*

Date.	Day of fast.	Total nitrogen.	Carbon.			β-oxybutyric acid.	
			Computed normal excretion. (A×0.79).	Determined.	Difference. (C−B)	Calculated. $\left(\frac{D\times100}{46.11}\right)$	Determined.
		A	B	C	D	E	F
1912.		gm.	gm.	gm.	gm.	gm.	gm.
Apr. 14–15	1st	7.10	5.61	5.82	0.21	0.46	...
15–16	2d	8.40	6.64	7.99	1.35	2.93	0.5
16–17	3d	11.34	8.96	10.35	1.39	3.01	2.1
17–18	4th	11.87	9.38	11.88	2.50	5.42	3.5
18–19	5th	10.41	8.22	10.69	2.47	5.36	2.1
19–20	6th	10.18	8.04	10.42	2.38	5.16	3.5
20–21	7th	9.79	7.73	9.06	1.33	2.88	2.8
21–22	8th	10.27	8.11	10.30	2.19	4.75	1.6
22–23	9th	10.74	8.48	10.92	2.44	5.29	3.5
23–24	10th	10.05	7.94	9.92	1.98	4.29	3.5
24–25	11th	10.25	8.10	9.59	1.49	3.23	1.4
25–26	12th	10.13	8.00	9.05	1.05	2.28	2.4
26–27	13th	10.35	8.18	10.15	1.97	4.27	4.2
27–28	14th	10.43	8.24	9.95	1.71	3.71	4.7
28–29	15th	8.46	6.68	8.71	2.03	4.40	1.6
29–30	16th	9.58	7.57	11.39	3.82	8.28	5.2
Apr. 30–May 1	17th	8.81	6.96	10.91	3.95	8.57	3.6
May 1–2	18th	8.27	6.53	9.65	3.12	6.77	4.4
2–3	19th	8.37	6.61	9.56	2.95	6.40	7.0
3–4	20th	7.69	6.08	8.07	1.99	4.32	4.4
4–5	21st	7.93	6.26	8.59	2.33	5.05	5.0
5–6	22d	7.75	6.12	8.40	2.28	4.95	3.1
6–7	23d	7.31	5.77	7.25	1.48	3.21	6.0
7–8	24th	8.15	6.44	8.68	2.24	4.86	6.9
8–9	25th	7.81	6.17	8.58	2.41	5.23	4.4
9–10	26th	7.88	6.23	8.56	2.33	5.05	6.1
10–11	27th	8.07	6.38	8.23	1.85	4.01	4.0
11–12	28th	7.62	6.02	7.73	1.71	3.71	4.9
12–13	29th	7.54	5.96	7.94	1.98	4.29	5.6
13–14	30th	7.83	6.19	7.95	1.76	3.82	5.4
14–15	31st	6.94	5.48	7.37	1.89	4.10	4.5
15–16	.....	4.83	3.82	7.13	3.31	7.18	.8
16–17	.....	3.81	3.01	4.28	1.27	2.75	.5
17–18	.....	[1]2.75	2.17	....	....	....	[1].5

[1]Determined in urine for about 22 hours.

The determination of β-oxybutyric acid by this method was so defective that it seems unwise to compute the amount of ammonia which would theoretically combine with the acid and to discuss any relationship arising therefrom.

Indirect computation of amounts of β-oxybutyric acid excreted.—In addition to the determinations made by the Black method, the amounts

of β-oxybutyric acid excreted were also computed by an indirect method, using the relationship between the nitrogen and the carbon. The carbon and the nitrogen in the urine were determined for every day of the fast and for the 3 food days following the fasting period. Normally there exists a relatively definite relationship between the carbon and the nitrogen of urine, a relationship which was determined by Munk on Breithaupt and Cetti as being not far from 1 part of nitrogen to 0.82 of carbon. This relationship was determined for L. for 2 days before the fast, and a ratio found, which may be termed "normal," of 1 to 0.79. We therefore computed the amount of carbon that would normally be excreted from the amount of nitrogen actually excreted, and deducted the result found from the total amount of carbon found in the urine. The excess carbon would be due, in all probability, to β-oxybutyric acid or to acetone bodies. The results of this computation are considered of sufficient importance to be included in table 38, which gives the total nitrogen for each day, the values for the normal excretion of carbon as computed with the ratio C : N = 0.79, the total carbon as actually determined, the difference which would be ascribed to β-oxybutyric acid, and finally the values for β-oxybutyric acid obtained by using 46.11 as the percentage of carbon in β-oxybutyric acid. As the values for β-oxybutyric acid actually determined are also given in this table, a comparison may readily be made.

In general the determined values are somewhat lower than those obtained by computation. Occasionally, especially toward the end of the fast, the determined values are higher than the calculated values. On the whole, however, there is sufficient agreement to give an approximate estimate as to the amount of β-oxybutyric acid present. Indeed, taking everything into consideration and the regularity of the figures, it would appear that the computed values are probably more nearly accurate than those which were actually determined. In any event, the amounts here found are noticeably less than those computed from the lævo-rotation of the urine observed by Brugsch with Succi and by Grafe with his fasting woman. When the computed values are compared, it is found that the greatest excretion of β-oxybutyric acid was from the sixteenth to the nineteenth days, when for 4 days an average amount of over 7 grams was excreted.

The amounts of β-oxybutyric acid present in these urines are not unlike those found in short fasting experiments or in experiments with a carbohydrate-free diet, and the stimulating effect of these acids upon metabolism is certainly not to be ignored. On the other hand, with the acid present in the body for so long a time, the subject might easily have become accustomed to its presence and therefore the reaction be less, as has been found in cases of severe diabetes.

It is perfectly clear, however, that the amounts of β-oxybutyric acid involved in these determinations are not sufficient to affect the respira-

tory quotients to an appreciable degree, since, as Magnus-Levy[1] has pointed out, the excretion of 20 grams of β-oxybutyric acid per day results in a lowering of the respiratory quotient only 0.006. The presence of this acid is, however, sufficient to account for the increase in the ammonia excretion as the fast continued. The effort of the body to correct this undue acidity by combining ammonia with the acid is thus clearly shown.

Bonniger and Mohr[2] found with Schenk much greater amounts of acid than were found or indeed calculated for the urine of L. Brugsch[3] likewise found large amounts with Succi, and the excretion for Grafe's[4] insane patient was also large. The uncertainty in the method for the quantitative determination of β-oxybutyric acid does not permit use of these values for comparison, and it is sufficient to state that lævorotatory β-oxybutyric acid in appreciable amounts is excreted in the urine during fasting.

Beginning on the afternoon of April 21, 1912, and continuing at least every other afternoon during the fast, a qualitative test for acetone in the breath was made, using the reagent of Scott-Wilson.[5] Several tests were also made each day after the fast, the latest being on May 17 at 7 p. m. In every case the test showed acetone present, but it is impossible to draw quantitative deductions from the results.

MINERAL METABOLISM.

With normal man the mineral metabolism has two main paths for excretion—through the solid salts of the urine and through the feces. With L. the entire mineral excretion took place through the urine, if one excepts the small amount of sodium chloride excreted through the skin. Usually much stress is laid upon the determination of the acid radicles in the urine, namely, chlorine, sulphur trioxide, and phosphorus pentoxide, and but little attention is given to the calcium, magnesium, potassium, and sodium metabolism. The important relationship between phosphorus and calcium and the possible draft upon the skeletal tissue of the body made the determination of the mineral constituents of the urine desirable, and although a very large number of determinations were made of the various components of the urine of our subject, it was possible, by combining and apportioning the material, to secure a sufficient sample of urine for the determination of the mineral constituents.

The analyses were made by Mr. J. C. Bock, who was at that time a member of the Laboratory staff and who had had previous experience in mineral analysis. Since special training was necessary for this inves-

[1]Magnus-Levy, Zeitschr. f. klin. Med., 1905. **56**, p. 83.
[2]Bonniger and Mohr, Zeitschr. f. exp. Path. u. Therapie, 1906, **3**, p. 675.
[3]Brugsch. Zeitschr. f. exp. Pathol. u. Therapie, 1905, **1**, p. 419.
[4]Grafe, Zeitschr. f. physiol. Chemie, 1910, **65**, p. 27.
[5]Scott-Wilson, Journ. Physiol., 1911, **42**, p. 444.

tigation of the mineral metabolism during fasting, Mr. Bock was allowed the privilege, through the kindness of Dr. Rufus S. Cole of the Rockefeller Hospital, of working with Dr. Francis H. McCrudden, at that time of the Rockefeller Hospital, and whose researches in mineral metabolism are too well known to need special mention here. Having acquired certain of Dr. McCrudden's methods and technique, Mr. Bock made a most careful analysis of the urine of L., determining the calcium, magnesium, sodium, and potassium, so that we have a fairly

TABLE 39.—*Mineral metabolism (urine excretion) in experiment with L.*

Date.	Day of fast.	Calcium (Ca).		Magnesium (Mg).		Potassium (K).		Sodium (Na).	
		Total.	Average per day.	Total.	Average per day.	Total.	Average per day.	Total.	Average per day.
1912.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Apr. 10–11	.....		0.307		0.034				
11–12	.....	1.228	.307	0.135	.034	.....	.....	.....	.....
12–13	.....		.307		.034				
13–14	.....		.307		.034				
14–15	1st.	.217	.217	.046	.046	1.630	1.630	2.070	2.070
15–16	2d.		.243		.106		1.368		.926
16–17	3d.	.729	.243	.317	.106	4.104	1.368	2.779	.926
17–18	4th.		.243		.106		1.368		.926
18–19	5th.		.274		.098		1.445		.276
19–20	6th.	.547	.274	.196	.098	2.889	1.445	.552	.276
20–21	7th.		.253		.070		.883		.154
21–22	8th.	.759	.253	.209	.070	2.650	.883	.463	.154
22–23	9th.		.253		.070		.883		.154
23–24	10th.		.220		.072		1.006		.100
24–25	11th.	.440	.220	.144	.072	2.012	1.006	.199	.100
25–26	12th.		.216		.065				
26–27	13th.	.432	.216	.129	.065	.....	.....	.....	.....
27–28	14th.		.236		.071		.814		.109
28–29	15th.	.471	.236	.141	.071	1.627	.814	.217	.109
29–30	16th.		.214		.078				
Apr. 30–May 1	17th.	.427	.214	.156	.078	.....	.....	.....	.....
May 1–2	18th.		.251		.059		.676		.051
2–3	19th.	.501	.251	.118	.059	1.351	.676	.102	.051
3–4	20th.		.237		.053		.644		.066
4–5	21st.	.474	.237	.105	.053	1.288	.644	.131	.066
5–6	22d.		.179		.050		.643		.083
6–7	23d.	.357	.179	.099	.050	1.285	.643	.166	.083
7–8	24th.		.167		.056		.787		.065
8–9	25th.	.334	.167	.111	.056	1.574	.787	.129	.065
9–10	26th.		.153		.051		.656		.055
10–11	27th.	.306	.153	.101	.051	1.312	.656	.109	.055
11–12	28th.		.131		.047		.585		.036
12–13	29th.	.262	.131	.093	.047	1.169	.585	.071	.036
13–14	30th.		.138		.052		.606		.053
14–15	31st.	.275	.138	.104	.052	1.212	.606	.105	.053
15–16	.....		.072		.019		.430		.054
16–17	.....	.144	.072	.037	.019	.859	.430	.107	.054
17–18[1]	.....	.096	.096	.008	.008	.116	.116	.046	.046

[1]Determinations in urine for about 22 hours.

complete picture of the mineral metabolism of this subject throughout the entire fast. As a rule, the urines for 2 days were combined, the determinations thus representing the amounts for 2-day periods. On two occasions it was necessary to combine the urines of 3 days, while the mineral metabolism was determined for the days preceding the fast on a sample representing the total urine for those 4 days. The results are given in table 39, the values per day for convenience being interpolated.

Throughout the entire fast there was a material excretion of all four of these elements. The calcium excretion remained relatively constant, with a slight tendency to fall off as the fast progressed, particularly after the third week. The highest amount, 0.274 gram per day, was observed on the fifth and sixth days of fasting; the smallest amount, 0.131 gram, was found on the twenty-eighth and twenty-ninth days of the fast.

With magnesium there was a very considerable increase in the first portion of the fast, and even for the last days of the fasting period the average was 0.052 gram, which was considerably more than the amount excreted per day in the four days prior to the fast, *i. e.*, 0.034 gram.

With the potassium there was a very great decrease as the fast progressed. The largest amount, 1.63 grams, was found on the first day of the fast, the excretion steadily falling until on the twenty-eighth and twenty-ninth days of the fast it reached 0.585 gram. It is interesting to note that at all times there was measurably over 0.5 gram of potassium excreted per day.

With sodium we find perhaps greater variations than for any other of these four substances, there being a rapid decrease for the first few days, followed by a more moderate but steady decrease for the remainder of the fast. The values range from 2.07 grams on the first day of the fast to 0.036 gram on the twenty-eighth and twenty-ninth days. It is thus seen that the decreases in the minerals excreted were by no means parallel.

Relationships of the Mineral Constituents.

In studying the mineral metabolism of the subject L. as indicated by the results of the urinary analyses given in table 39 we see instantly the great advantage in having the subject drink only distilled water, for the entire mineral output is then derived solely from the body tissue; we can therefore consider the relationships between calcium and magnesium and between sodium and potassium without the discussion being complicated by the possibility of varying amounts of these elements in the drinking-water.

While a continuous decrease is evident in the excretion of all four elements, it is likewise clear that the diminution in the excretion is more marked with sodium than with any other element. Fortunately the relations between potassium and sodium and calcium and magne-

sium in the animal body have been recently carefully studied,[1] and we may more advantageously study the excretion of these four elements by noting the ratios of their oxides to each other than in any other way. Consequently the percentages of calcium oxide and magnesium oxide excreted have been computed, using the total of the calcium oxide and magnesium oxide as 100. Similarly the potassium and sodium oxides have been added together and the percentages of potassium oxide and sodium oxide computed. These percentages, which are given in table 40, were computed for each sample of urine analyzed.

Prior to the fast there was about eight times as much calcium oxide excreted in the urine as magnesium oxide, but this relationship became 4 to 1 on the first fasting day and subsequently the percentages were fairly constant at approximately 75 per cent for the calcium oxide and 25 per cent for the magnesium oxide. It was not until the third day with food following the fast that this relationship was disturbed, when the original percentages prior to the fast were again approximated. According to these ratios, then, there were relatively much larger amounts of magnesium excreted during fasting than on the food days.

In considering the ratios for the potassium oxide and sodium oxide, we find that the problem is considerably complicated by the fact that a certain amount of sodium chloride exists in the body which is very loosely, if at all, combined in the tissues. Consequently, on the first day of the fast, only 41.3 per cent of the total alkali was found in the form of potassium oxide and 58.7 per cent in the form of sodium oxide. On the next day the proportion was reversed, and from that time until the eighteenth day there was a tendency toward a gradually increasing percentage of potassium oxide. For the remaining days of the fast, about 90 per cent of the alkali was in the form of potassium oxide and 10 per cent or less in the form of sodium oxide. One specimen of urine—that for the twenty-eighth and twenty-ninth days—shows the high percentage of 93.6 for potassium oxide as compared with 6.4 per cent for sodium oxide.

It is obvious from the values for the potassium and sodium that shortly after the excretion of the uncombined sodium chloride on the first few days, the body excreted the potassium and sodium from muscle substance and we then have the large differences between these two elements; in the last part of the fast, approximately nine or ten times more potassium was excreted than sodium. This far exceeded the ordinary proportion between potassium and sodium in muscle given as a result of the analyses of Bunge.[2]

The relationship between calcium and magnesium in animal tissues has been extensively studied, particularly with dogs and horses.

[1] Gérard, Ann. de l'Inst. Pasteur, 1912, **26**, p. 12.

[2] See Aron, Oppenheimer's Handbuch der Biochemie des Menschen u. der Tiere, 1909, **1**, p. 84, where the relationship is given as 5 to 6 times as much potassium as sodium.

TABLE 40.—*Distribution of mineral metabolism (urine excretion) in experiment with L.*

Date.	Day of fast.	Calcium and magnesium.					Potassium and sodium.				
			CaO.		MgO.			K_2O.		Na_2O.	
		Total. (grams)	Grams.	Per cent. $(\frac{B \times 100}{A})$	Grams.	Per cent. $(\frac{D \times 100}{A})$	Total. (grams)	Grams.	Per cent. $(\frac{G \times 100}{F})$	Grams.	Per cent. $(\frac{I \times 100}{F})$
		A	B	C	D	E	F	G	H	I	J
1912.											
Apr. 10–11											
11–12		1.942	1.718	88.5	0.224	11.5					
12–13											
13–14											
14–15	1st.	0.381	0.304	79.8	0.077	20.2	4.752	1.964	41.3	2.788	58.7
15–16	2d.										
16–17	3d.	1.545	1.020	66.0	0.525	34.0	8.688	4.944	56.9	3.744	43.1
17–18	4th.										
18–19	5th.										
19–20	6th.	1.090	0.765	70.2	0.325	29.8	4.224	3.480	82.4	0.744	17.6
20–21	7th.										
21–22	8th.	1.409	1.062	75.4	0.347	24.6	3.816	3.192	83.6	0.624	16.4
22–23	9th.										
23–24	10th.										
24–25	11th.	0.854	0.616	72.1	0.238	27.9	2.692	2.424	90.0	0.268	10.0
25–26	12th.										
26–27	13th.	0.819	0.604	73.7	0.215	26.3					
27–28	14th.										
28–29	15th.	0.893	0.659	73.8	0.234	26.2	2.253	1.960	87.0	0.293	13.0
29–30	16th.										
Apr. 30–May 1	17th.	0.856	0.597	69.7	0.259	30.3					
May 1– 2	18th.										
2– 3	19th.	0.897	0.701	78.1	0.196	21.9	1.766	1.628	92.2	0.138	7.8
3– 4	20th.										
4– 5	21st.	0.838	0.664	79.2	0.174	20.8	1.728	1.552	89.8	0.176	10.2
5– 6	22d.										
6– 7	23d.	0.664	0.500	75.3	0.164	24.7	1.772	1.548	87.4	0.224	12.6
7– 8	24th.										
8– 9	25th.	0.652	0.468	71.8	0.184	28.2	2.070	1.896	91.6	0.174	8.4
9–10	26th.										
10–11	27th.	0.596	0.428	71.8	0.168	28.2	1.726	1.580	91.5	0.146	8.5
11–12	28th.										
12–13	29th.	0.520	0.366	70.4	0.154	29.6	1.504	1.408	93.6	0.096	6.4
13–14	30th.										
14–15	31st.	0.558	0.385	69.0	0.173	31.0	1.602	1.460	91.1	0.142	8.9
15–16											
16–17		0.263	0.202	76.8	0.061	23.2	1.179	1.035	87.8	0.144	12.2
17–18[1]		0.147	0.134	91.2	0.013	8.8	0.203	0.140	69.0	0.063	31.0

[1]Determinations in urine for about 22 hours.

Toyonaga[1] in Tokio found that in the muscles there is always less calcium than magnesium, thus confirming the analyses of Katz,[2] but in the glands there is always more calcium than magnesium.

Aloy,[3] studying the calcium and magnesium content of muscle, found about twice as much magnesium as calcium. Perhaps of more interest

[1]Toyonaga, Bul. Coll. of Agr., Tokio, 1902–1903, **5**, p. 143, and p. 455; also 1904–1905, **6**, pp. 89 and 357.

[2]Katz, Archiv f. d. ges. Physiol., 1896, **63**, p. 1.

[3]Aloy, Compt. rend. Soc. Biol., 1902, **54**, p. 604.

in this particular study are the observations of Magnus-Levy,[1] who analyzed the body of a man who had committed suicide. His results showed about three times as much magnesium as calcium in the muscles. On the basis of all the analyses prior to those of Magnus-Levy, Aron[2] gives the average figure for the relationship of magnesium to calcium in the muscle of dogs as 1 to 0.54–0.60 and in the muscle of horses as 1 to 0.34. In general, then, we may assume that there is approximately three times as much magnesium as calcium in the muscle of man.

We may consider the magnesium excretion as more nearly an index of the muscle disintegration than calcium, for while there is, to be sure, a small percentage of magnesium oxide in bone, there is a much larger available supply of calcium oxide in the form of bone which is unquestionably drawn upon. The calcium-oxide excretion is therefore the resultant of two factors, *i. e.*, muscle disintegration and bone disintegration, while magnesium oxide is derived almost exclusively from the non-osseous tissue.

It is a matter of regret that the small amount of magnesium present in the urine and the necessity for combining the samples for several days renders it very difficult to make an exact comparison between the magnesium excretion and the other urinary constituents. In general, however, the magnesium excretion follows approximately the nitrogen excretion. Of striking interest is the fact that, on the first day of the fast, an extraordinarily low amount of both magnesium and calcium were excreted. The increment in the magnesium excretion on the second day (*i. e.*, 100 per cent) was not approximated by the excretion of any other element in the body.

The results of the analyses reported by Cathcart for Beauté, while relatively few in number, are in full conformity with our findings, save that the magnesium excretion on the days prior to the fast is much larger than that found with L. Furthermore, L. excreted considerably more calcium per day than did Beauté during the fasting period.

In the food period following the fast, it is interesting to note the striking fall in the excretion of all of the minerals save sodium. For the first 2 food days there was but half as much calcium excreted as on the last day of the fast, about one-third as much magnesium, seven-tenths as much potassium, and about the same amount of sodium. On the last day of the food period after the fast, the calcium was seven-tenths that of the last fasting day, the magnesium one-seventh, the potassium one-fifth, and the sodium about the same as on the last fasting day.

The amounts of calcium, magnesium, potassium, and sodium intake are unknown for these days, yet these elements must have been present in the food taken. It is obvious that the effect of the ingestion of a large

[1]Magnus-Levy, Biochem. Zeitschr., 1910, **24**, p. 363.

[2]Aron, Oppenheimer's Handbuch der Biochemie des Menschen u. der Tiere, 1909, **1**, p. 88.

amount of carbohydrates upon the mineral metabolism was considerable, resulting in a marked retention of the inorganic salts introduced, with a noticeable lessening in the attack upon the storage of mineral matter in the body. On the other hand, it should be remembered that on these days fecal matter was passed in considerable amounts and we may have here to deal only with the disturbance in the paths of excretion of mineral matter. Thus, in the total amount of fecal material excreted between 5 p. m. and 8 a. m. on the first food day following the fast, there were excreted 1.78 grams of calcium oxide and 0.748 gram of magnesium oxide, as determined by Mr. Bock on the dry matter of feces. On this basis 30 per cent of the earthy alkali was magnesium.

REDUCING POWER.

The presence, even in fasting urines, of reducing substances other than dextrose, has frequently been noted. Munk[1] especially has studied this subject and made extensive observations of the reducing power of the urines in Breithaupt's experiment, using a reduction method developed by himself[2] and further elaborated and tested by Hagemann.[3] Munk's method gives as the reducing power for normal urines from 0.16 to 0.47 per cent, with an average of 0.3 per cent. In the fasting experiment with Breithaupt he found in the urine of the last 2 food days as high as 7.7 grams of reducing substance (calculated as dextrose). Even in fasting periods amounts were obtained ranging from 3 to 7 grams per day.[4] Furthermore, he noted very considerable fluctuations from day to day. Munk considers the reducing action to be due in large part to the formation of glykuronic acid. The reducing power of the urine bore no relationship to the amount of carbohydrate ingested, but there was a tendency to parallel the protein disintegrated. In connection with the experiment with L., Dr. A. W. Peters suggested that it would be desirable to test the reducing power of the urine. As Dr. Peters had previously developed an accurate method[5] for testing the amounts of reducing substances in urine, this could be done to advantage, and accordingly the determinations were made for each day of the fast by W. F. O'Hara under Dr. Peters's supervision. The results, expressed in terms of dextrose, are given in table 41.

The Peters method gives considerably less reducing substance in the urine than the method of Munk. Thus, for normal urines, Peters has found in this laboratory from 0.03 to 0.12 per cent as compared with the values of 0.16 to 0.47 per cent found by Munk. Since the observations of the urine in our fasting experiment were to be wholly comparative, either method was suitable for studying the variations in the

[1]Munk, Archiv f. path. Anat. u. Physiol., 1893, **131**, Supp., p. 138.
[2]Munk, Archiv f. path. Anat. u. Physiol., 1886, **105**, p. 73.
[3]Hagemann, Archiv f. d. ges. Physiol., 1888, **43**, p. 501.
[4]Munk, Archiv f. path. Anat. u. Physiol., 1893, **131**, Supp., p. 68, table 7.
[5]See description of method by Dr. Peters in Benedict and Joslin, Carnegie Inst. Wash. Pub. 176, 1912, p. 8.

reducing power as the fast progressed, regardless of any inherent differences which might exist in the two methods.

The reducing power of the fasting urines in the experiment with L. was at all times well within normal limits, averaging not far from the values observed on control normals in this laboratory. The largest amount on the fasting days was 498 milligrams for the fourth and sixteenth days, and the smallest amount was 296 milligrams for the third and sixth days.

A large amount of reducing power was found on the first day of food following the fast. On this day the subject ate in a relatively short time about 500 grams of carbohydrate, chiefly in the form of soluble

TABLE 41.—*Total reducing power of urine in experiment with L.*

Date.	Day of fast.	Reducing power (as dextrose).	Date.	Day of fast.	Reducing power (as dextrose).
1912.		*mg.*	1912.		*mg.*
Apr. 14–15	1st	450	May 1– 2	18th	396
15–16	2d	414	2– 3	19th	376
16–17	3d	296	3– 4	20th	376
17–18	4th	498	4– 5	21st	312
18–19	5th	328	5– 6	22d	342
19–20	6th	296	6– 7	23d	328
20–21	7th	376	7– 8	24th	376
21–22	8th	376	8– 9	25th	356
22–23	9th	414	9–10	26th	376
23–24	10th	356	10–11	27th	328
24–25	11th	342	11–12	28th	342
25–26	12th	396	12–13	29th	376
26–27	13th	343	13–14	30th	396
27–28	14th	384	14–15	31st	342
28–29	15th	328	15–16	.....	4441
29–30	16th	498	16–17	.....	267
Apr. 30–May 1	17th	434	17–18	.....	[1]246

[1]Determined in urine for about 22 hours.

dextrose, the diet consisting of honey and the juice of grapes, oranges, and lemons. Unquestionably this amount exceeded his carbohydrate tolerance on that day and 4.44 grams of dextrose were therefore excreted in the urine. It is possible that we find here with man the condition with dogs described by Hofmeister[1] as "hunger diabetes," and it may be an interesting confirmation of his theory.

Recently, also, Rietschel[2] has noted that the fasting of infants has resulted in a marked lowering of their tolerance for carbohydrate substances. This lowering has been so noticeable as to lead Rietschel to warn clinicians in the following words against the undue use of starving in treating pathological cases:

"Dass der Hunger spez. die absolute Nahrungsentziehung für den gesunden, wie besonders für den ernährungsgestörten Säugling auch schwere Gefahren nach sich ziehen kann, ist heute allgemein anerkannt."

[1]Hofmeister, Archiv f. exp. Path. u. Pharm., 1889–1890, **26**, p. 355.
[2]Rietschel, Heubner's Festschrift, Berlin, 1913, p. 516.

To attempt an analysis of the reducing substances in the urine during the fasting period would be somewhat difficult. A certain portion has already been ascribed to creatinine and to uric acid, but there is no definite relationship between the amounts of uric acid, creatinine, and the reducing power to be noted in the results obtained in this fasting experiment.

CARBON IN URINE.

While the excretion of carbon in the form of carbon dioxide is of great significance as indicating the total amount of energy transformed into heat in the body, nevertheless when a study of the total loss of body material is of importance, as it is during complete fasting, the carbon in the urine must be taken into consideration. Since we were also making a study of the energy output of the urine by burning samples in a calorimetric bomb, it was relatively simple to combine the determinations of the energy output and the carbon content. Consequently, after the dried urine had been burned inside the bomb, the carbon dioxide produced in the combustion was allowed to escape from the vessel through weighed soda-lime tubes, in accordance with the method of Fries.[1] These determinations were skilfully carried out by Mr. A. W. Cornell, of the Laboratory staff.

The description of the method of preparation and drying of the urine samples for the bomb calorimeter has already been given in the discussion of the total solids in the urine.[2] From the weight of the carbon dioxide in the soda-lime tubes and the weight of the urine, the amount of carbon per day excreted in the urine is readily computed. These values are given in table 42.

The determination of carbon in urine has been for many years a subject of research in this laboratory and in the chemical laboratory of Wesleyan University. Various methods have been tried, including the moist combustion process, drying with and without the addition of salicylic acid, and with and without the use of the cellulose filter blocks recommended by Kellner.[3] The method which gives the largest percentage of carbon is presumably the best one, and this has been our criterion. No method that we have thus far used approaches the large percentage of carbon which is obtained by the method previously described,[4] namely, drying first with 50 milligrams of salicylic acid, then transferring to a nickel capsule, drying in a desiccator until ready to burn, and finally burning in compressed oxygen in a bomb calorimeter, and allowing the carbon dioxide to escape into soda-lime. When the heat of combustion is desired, the determination of carbon occupies but a few moments additional, thus providing the simplest and best method for obtaining the required values. The preliminary operations of drying require but little attention from the assistant.

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[1] Fries, Journ. Am. Chem. Soc., 1909, **31**, p. 272.
[2] See p. 243.
[3] Kellner, Landw. Jahrb., 1896, **47**, p. 297.
[4] Higgins and Benedict, Am. Journ. Physiol, 1911, **28**, p. 291.

The total amount of carbon excreted in the urine ranged, according to the values in table 42, from 5.82 grams on the first day of the fast to 11.88 grams on the fourth day of the fast. In the first half of the fasting period the carbon excretion averaged somewhat above 10 grams per day, but in the latter part the excretion was not far from 8 grams.

TABLE 42.—*Nitrogen, carbon, and energy of urine in experiment with L.*

Date.	Day of fast.	Nitrogen.	Carbon.	Carbon per gram of nitrogen. (C : N)	Energy of urine.		
					Total.	Per gram of nitrogen. (Cals. : N)	Per gram of carbon. (Cals. : C)
1912.		*gm.*	*gm.*	*gm.*	*cals.*	*cals.*	*cals.*
Apr. 12–13	.....	14.48	11.41	0.788	129	8.91	11.30
13–14	.....	11.54	9.08	.787	104	9.01	11.45
14–15	1st....	7.10	5.82	.820	65	9.15	11.17
15–16	2d.....	8.40	7.99	.951	89	10.60	11.14
16–17	3d.....	11.34	10.35	.913	118	10.40	11.40
17–18	4th....	11.87	11.88	1.001	134	11.29	11.28
18–19	5th....	10.41	10.69	1.027	123	11.82	11.51
19–20	6th....	10.18	10.42	1.024	116	11.40	11.13
20–21	7th....	9.79	9.06	.925	104	10.62	11.48
21–22	8th....	10.27	10.30	1.003	116	11.30	11.26
22–23	9th....	10.74	10.92	1.017	124	11.54	11.35
23–24	10th....	10.05	9.92	.987	111	11.04	11.19
24–25	11th....	10.25	9.59	.936	110	10.73	11.47
25–26	12th....	10.13	9.05	.893	105	10.36	11.60
26–27	13th....	10.35	10.15	.981	114	11.01	11.23
27–28	14th....	10.43	9.95	.954	111	10.64	11.16
28–29	15th....	8.46	8.71	1.030	95	11.23	10.91
29–30	16th....	9.58	11.39	1.189	123	12.84	10.80
Apr. 30–May 1	17th....	8.81	10.91	1.238	117	13.28	10.72
May 1– 2	18th....	8.27	9.65	1.167	104	12.58	10.78
2– 3	19th....	8.37	9.56	1.142	105	12.54	10.98
3– 4	20th....	7.69	8.07	1.049	91	11.83	11.28
4– 5	21st....	7.93	8.59	1.083	95	11.98	11.06
5– 6	22d.....	7.75	8.40	1.084	93	12.00	11.07
6– 7	23d.....	7.31	7.25	.992	88	12.04	12.14
7– 8	24th....	8.15	8.68	1.065	95	11.66	10.94
8– 9	25th....	7.81	8.58	1.099	91	11.65	10.61
9–10	26th....	7.88	8.56	1.086	90	11.42	10.51
10–11	27th....	8.07	8.23	1.020	90	11.15	10.94
11–12	28th....	7.62	7.73	1.014	85	11.15	11.00
12–13	29th....	7.54	7.94	1.053	87	11.54	10.96
13–14	30th....	7.83	7.95	1.015	87	11.11	10.94
14–15	31st....	6.94	7.37	1.062	80	11.53	10.85
15–16	.....	4.83	7.13	1.476	74	15.32	10.38
16–17	.....	3.81	4.28	1.123	45	11.81	10.51

In the fasting experiments at Wesleyan University the carbon content of the urine increased noticeably on a number of days as the fast continued. This increase in carbon was accompanied by an increase in the energy content, which was attributed at the time to the presence of a large amount of β-oxybutyric acid. A similar increment in the carbon content of fasting urine was noted with an insane patient by Benedict and Diefendorf.[1] This excess of carbonaceous material

[1]Benedict and Diefendorf, Am. Journ. Physiol., 1907, **18**, p. 362.

became apparent when the ratio between the carbon and nitrogen of normal urine was compared with that obtained in these fasting experiments.

Carbon-Nitrogen Ratio.

Since the carbon content of the urine naturally fluctuates to a certain degree with the nitrogen content, it is obvious that the determinations of the carbon alone would not have the significance of the ratio between the carbon and nitrogen, for we are interested not so much in the carbon normally accompanying nitrogen in the urine as in the carbon other than that in nitrogenous material. With an ordinary diet, essentially constant ratios have been found for normal urines by various investigators, averaging not far from 0.8 gram of carbon for each gram of nitrogen excreted in the urine. Thus Benedict and Milner[1] found an average carbon-nitrogen ratio of 0.73 for 58 metabolism experiments upon normal individuals with rest and work in the respiration calorimeter at Wesleyan University. The variations in these experiments were, in general, very small, the carbon-nitrogen ratio ranging from 0.67 to 0.89. Richardson,[2] working with fewer urines, obtained a carbon-nitrogen ratio varying from 0.74 to 1.01, with an average of 0.88. Magnus-Alsleben[3] concludes that with healthy individuals the carbon-nitrogen ratio will not pass beyond the limits of 0.7 and 1.0, regardless of diet. Loewy,[4] Pregl,[5] Reale,[6] and others reported values with normal individuals essentially within these limits.

The composition of the diet seems to have but little effect upon this ratio. Benedict and Milner noted no appreciable variation due to change in diet containing a preponderance of either carbohydrate or fat, but Tangl[7] found an average ratio of 0.96 on days when the diet was rich in carbohydrates and poor in fat, which was considerably higher than the average carbon-nitrogen ratio of 0.75 which was found when the diet was poor in carbohydrate and rich in fat. Notwithstanding the fact that the diet on these days was extraordinary, it may be noted that Tangl's figures fell within the limits set by Magnus-Alsleben.

Moderate muscular work has been shown both by Tangl and by Benedict and Milner to increase the ratios little, if any, over those for rest, although the severe muscular exercise incidental to the strenuous work of a Marathon race was found by Higgins and Benedict[8] to result in distinctly abnormal carbon-nitrogen ratios in a number of cases, a ratio as high as 1.517 being found in one instance.

[1]Benedict and Milner, U. S. Dept. Agr., Office Expt. Sta. Bul. 175, 1907, p. 145.
[2]Richardson, Bulletin Mt. Hope Retreat Laboratory, 1900. Cited in Maly's Jahrsb. d. Tier-Chemie, 1901, **31**, p. 703.
[3]Magnus-Alsleben, Zeitschr. f. klin. Med., 1909, **68**, p. 358.
[4]Loewy, Verhndl. der physiol. Gesellsch. zu Berlin, 1905–1906, p. 11.
[5]Pregl, Archiv f. d. ges. Physiol., 1899, **75**, p. 87.
[6]Reale, Biochem. Zeitschr., 1912, **47**, p. 355.
[7]Tangl, Archiv f. Anat. u. Physiol., 1899, Physiol. Abth. Supp., p. 251.
[8]Higgins and Benedict, Am. Journ. Physiol., 1911, **28**, p. 291.

With normal urines, therefore, one may conclude that the carbon-nitrogen ratio may vary from 0.67 to 1.0. Many interesting cases are recorded in which the disturbance of the carbon-nitrogen ratio has been found. In the fasting experiments at Wesleyan University carbon-nitrogen ratios during fasting ranged from a minimum of 0.660 to a maximum of 1.293. On 7 days out of 43 the ratio was over 1, these 7 days being the last 4 days of a 7-day fast and the last 3 of a 4-day fast. In certain types of fever, also, Magnus-Alsleben[1] found an increase of the carbon-nitrogen ratio, while in others there was a marked decrease. He also reports three cases in which extremely high ratios were obtained after severe muscular work, these ratios being 3.262, 1.926, and 1.038 respectively. It is thus clear that under conditions which result in an abnormal katabolism, disturbances in the carbon-nitrogen ratio are found, and conversely a disturbance of this ratio may be taken as *prima facie* evidence of a distinctly disturbed katabolism.

The carbon-nitrogen ratio has been computed for each day of the fasting experiment with L. and likewise for the food days prior and subsequent to the fast. These values are included in table 42, together with the values for the total nitrogen. On the 2 days before the fast the ratio was very constant, averaging 0.79. It then rose rapidly until the fourth day, when it was slightly over 1.0 and remained at approximately 1 until the maximum level was reached between the sixteenth and nineteenth days of fasting. The very high value of 1.476 on the first day with food after the fast is in part explained by the excretion of 4.44 grams of dextrose in the urine. It is seen from these ratios, therefore, that the urine excretion after the first day or two regularly contained some nitrogen-poor and carbon-rich substance which, from all evidence, appears to be β-oxybutyric acid. Since the 2 days with food before the fast agree so perfectly, we have felt justified in using the average value of 0.79 for computing the normal amount of carbon accompanying nitrogen in the indirect computation of the amount of β-oxybutyric acid present in the urine. (See column B, table 38, page 283.)

The values found with L. during fasting are materially higher throughout the entire fast than those reported by Munk for Breithaupt, for on 6 days of the fast Munk found no difference in the carbon-nitrogen ratio between the fasting days and the 2 days with food following the fast. On the last 6 days of a 3-weeks fast Grafe[2] found extraordinarily high carbon-nitrogen ratios as follows: 1.714, 1.642, 2.016, 1.873, 1.63, 1.53. On the first food day the ratio fell to 0.746. The three observations of Pettenkofer and Voit[3] may also be cited, these investigators finding on the first fasting day an average of 0.7 as the carbon-nitrogen ratio.

[1]Magnus-Alsleben, Zeitschr. f. klin. Med., 1909, **68**, p. 358.
[2]Grafe, Zeitschr. f. Physiol. Chem., 1910, **65**, p. 21.
[3]Pettenkofer and Voit, Zeitschr. f. Biol., 1866, **2**, p. 459.

ENERGY OF URINE.

In studying the metabolism of a fasting man, although we are particularly interested in the energy transformed in the body and leaving the body as heat, a complete picture of the total breaking-down of tissue and loss of body material can not be had without a knowledge of the potential energy of unoxidized material in the urine throughout the fasting period. Determinations of the heat of combustion were made by Mr. A. W. Cornell, the results given in table 42 being always the average of two or three well-agreeing analyses.

During the fasting period the total amount of energy lost in the urine ranged from 65 calories on the first day to 134 calories on the fourth day. There was a general tendency after the fourth day for the values to fall off gradually as the fast continued; excluding the first day, the smallest amount (80 calories) was found on the last day of the fast. The energy was also determined for the 2 days immediately preceding the fast, the values being 129 and 104 calories respectively. On the days with food following the fast, very small amounts of energy were found, these being 74 calories on the first and 45 calories on the second food day.

CALORIE-NITROGEN RATIO.

Since the total amount of energy lost per day may vary with the amount of nitrogen excreted, and since there will always be a certain amount of potential energy normally accompanying each gram of nitrogen in the urine, it is important to compute the number of calories per gram of nitrogen. The results of such computation are also given in table 42.

On the 2 days before the fast, there were about 9 calories daily per gram of nitrogen. The ratio remained practically unchanged on the first day of the fast, but for the next 4 days it showed a distinct tendency to increase. The highest ratio found during the fasting period was 13.28 calories per gram of nitrogen on the seventeenth day, and the lowest was 9.15 calories on the first day of the fast. It is thus seen that, except on the first day, the ratios throughout the fast were comparatively high, exceeding those found for the preceding food days. The ratios for the 2 days with food following the fast are influenced by the fact that on the first day, when the diet contained an excessive amount of carbohydrate, there was a measurable amount of sugar excreted (4.44 grams), which would obviously increase the energy but have no effect upon the nitrogen; furthermore, on the second day a very small amount of nitrogen was excreted. Neither of these values can of course be looked upon as obtained under normal conditions.

With normal subjects and an ordinary diet, the ratio of calories to nitrogen is essentially constant. Thus Benedict and Milner[1] found

[1]Benedict and Milner, U. S. Dept. Agr., Office Exp. Sta. Bull. 175, 1907, p. 145.

an average calorie-nitrogen ratio of 8.09 for 58 rest and work experiments with normal individuals in the respiration calorimeter at Wesleyan University, the variations being extremely small, ranging from 7.3 to 8.94. When unbalanced diets are taken, this ratio may be somewhat altered. Tangl[1] reports the ratio considerably higher on the days when the diet was rich in carbohydrates and poor in fat, the ratio becoming as high as 11.67 on the carbohydrate-rich days and falling to 9.63 on the carbohydrate-poor days. On the other hand, Benedict and Milner noted no appreciable change due to diet.

In the earlier fasting experiments the energy in the urine has been rarely determined, the most extensive investigation being that in Wesleyan University;[2] in one experiment a calorie-nitrogen ratio was found ranging from 8.0 to 19.75.

The large ratios found during fasting experiments are unquestionably to be explained by an excretion of nitrogen-poor, carbon-rich material, which is chiefly β-oxybutyric acid. Unfortunately, in the earlier observation of Benedict and Diefendorf, in which the very high ratio of 19.75 was found, direct evidence of the excretion of β-oxybutyric acid was not obtained, as the determinations were not then feasible. Assuming that the high calorie-nitrogen ratio is due to the presence of acetone bodies, it can be seen that during the fasting experiment of the subject L. the highest acidosis as measured by this means occurred between the fifteenth and twenty-fifth days, high ratios prevailing for this entire period.

Calorie-Carbon Ratio.

While it is perfectly possible to have a carbon-rich, nitrogen-free substance in the urine which would profoundly affect the calorie-nitrogen ratio, the presence of carbonaceous material in all energy-producing material found in urine would lead one to suppose that the relationship between calories and carbon would be much more regular than that between the calories and the nitrogen. The calorie-carbon ratios have been computed for this experiment and are included in table 42. The striking irregularities in the other ratios given in this table are entirely absent in the calorie-carbon ratio, for they remain remarkably constant under all conditions. The values for the entire series, including both the first and second food periods, range only between 12.14 on the twenty-third day of the fast and 10.38 on the first day with food after the fast. In the fasting period itself the minimum value was 10.51 on the twenty-sixth day. It is thus seen that during the total 31 days of the fast there were, on the average, 11.12 calories for each gram of carbon.

The average calorie-carbon ratio in these fasting urines, namely, 11.12 calories, is almost exactly the same as that found by Higgins and

[1]Tangl, Archiv f. Anat. u. Physiol., 1899, Physiol. Abth. Supp., p. 251.

[2]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 493, and Benedict and Diefendorf, Am Journ. Physiol., 1907, 18, p. 362.

Benedict,[1] their average calorie-carbon ratio for 18 specimens of urine excreted after severe muscular exercise incidental to a Marathon race being 11.02. This is also very close to the average calorie-carbon ratio obtained by Benedict and Milner, namely, 10.96. The striking uniformity in the ratio between calories and carbon again emphasizes the importance of the development of some simple, rapid method of determining the carbon in urine which will not require the employment of a complicated bomb calorimeter.

Still another relationship may be studied by comparing the total potential energy in the urine with the total estimated heat output. This comparison, however, is made in another section of the report. (See table 64, page 414.) The values given in this table show clearly that the total amount of energy excreted in the urine by the fasting subject L. equals approximately 8 to 10 per cent of the daily quota, and hence may not be neglected in any consideration of the energy lost by this man as the fast continued.

[1]Higgins and Benedict, Am. Journ. Physiol., 1911, **28**, p. 291.

MICROSCOPY OF URINE AND TESTS FOR ALBUMIN.

By Harry W. Goodall, M. D.

The heat test was used in making the albumin determinations. For the sake of uniformity the microscopic examination was made as follows: Two 15 mm. × 15 mm. cover-glass fields were examined with each specimen, 20 minutes being given to searching for and counting casts. The urine was centrifuged at a uniform rate for 5 minutes. The results of the tests are given herewith.

DETAILED RESULTS.

April 14–15 (first day of fast).—*Albumin*, absent. *Sediment*, no casts, blood, or pus; rare round cell, occasional squamous cell; little mucus.

April 15–16 (second day of fast).—*Albumin*, absent. *Sediment*, no casts or pus; rare normal red blood corpuscle, rare small round cell, occasional squamous cell; little mucus.

April 16–17 (third day of fast).—*Albumin*, absent. *Sediment*, one hyaline cast, small diameter, no blood or pus; few small round cells, rare large caudate cell, numerous squamous cells; rare spermatozoa, normal in appearance; little mucus.

April 17–18 (fourth day of fast).—*Albumin*, absent. *Sediment*, no casts, blood, or pus; few small round and squamous cells, little mucus.

April 18–19 (fifth day of fast).—*Albumin*, slightest possible trace. *Sediment*, 13 hyaline casts, 3 coarse granular casts, all of large diameter; a few of the casts with cells adherent; small round cells more numerous; few squamous cells.

April 19–20 (sixth day of fast).—*Albumin*, least possible trace. *Sediment*, 15 hyaline casts, 2 coarse granular casts, nearly all of large diameter, some with cells adherent; few small round and squamous cells.

April 20–21 (seventh day of fast).—*Albumin*, slightest possible trace. *Sediment*, 5 hyaline casts, 9 coarse granular cells, all of large diameter, some with cells adherent; rare normal red blood globule, numerous small round cells, few squamous cells; rare spermatozoa, normal in appearance.

April 21–22 (eighth day of fast).—*Albumin*, slightest possible trace. *Sediment*, 4 hyaline casts, 5 coarse granular casts, nearly all of large diameter, some with cells adherent; numerous medium and small round cells; rare small caudate cell; little mucus.

April 22–23 (ninth day of fast).—*Albumin*, slightest possible trace. *Sediment*, 5 hyaline casts, three of which had a few cells and fat drops adherent; 5 coarse granular casts with cells adherent, all casts of large diameter; no blood or pus; few small and medium round and squamous cells; rare spermatozoa, normal in appearance.

April 23–24 (tenth day of fast).—*Albumin*, slightest possible trace (albumin cloud more marked than at previous examinations). *Sediment*, 8 hyaline casts, some with cells and fat drops adherent; 4 coarse granular casts; all casts of large diameter; no blood or pus; few small and medium round and squamous cells; little mucus.

April 24–25 (eleventh day of fast).—*Albumin*, slightest possible trace (same as last examination). *Sediment*, 4 hyaline casts; 3 coarse granular casts; general tendency to diminution in diameter of casts; adherent cells and fat drops less numerous; few small and medium round and squamous cells.

April 25–26 (twelfth day of fast).—*Albumin*, least possible trace (same as last examination). *Sediment*, 7 hyaline casts, 6 coarse granular casts, chiefly small diameter; few fat drops and cells adherent; few leucocytes and small round cells; few acid sodium-urate crystals; little mucus.

April 26–27 (thirteenth day of fast).—*Albumin*, slightest possible trace (reaction less marked). *Sediment*, 15 hyaline casts; 2 coarse granular casts of medium size and with a few cells adherent; few leucocytes and small round cells.

April 27–28 (fourteenth day of fast).—*Albumin*, slightest possible trace (same as last examination). *Sediment*, 6 hyaline casts, 2 coarse granular casts, all casts of medium size and with a few cells adherent; few leucocytes and small round cells; numerous spermatozoa.

April 28–29 (fifteenth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 15 hyaline casts; 10 coarse granular casts, few cells and fat drops adherent; general tendency to decrease in diameter of casts; few small and medium round cells; rare small caudate and neck-of-bladder cells.

April 29–30 (sixteenth day of fast).—*Albumin*, slightest possible trace (same as last examination). *Sediment*, 14 hyaline casts; 12 coarse granular casts, chiefly of small diameter; few small and medium round cells; rare neck-of-bladder cells.

April 30–May 1 (seventeenth day of fast).—*Albumin*, slightest possible trace (very faint reaction).—*Sediment*, 7 hyaline casts, 2 fine granular casts, some with few fat drops and cells adherent; casts of small diameter; few small and medium round cells; rare neck-of-bladder cells; few squamous cells.

May 1–2 (eighteenth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 8 hyaline casts; 4 coarse granular casts, small diameter, few fat drops and cells adherent; few small and medium round cells; few squamous cells.

May 2–3 (nineteenth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 8 hyaline casts; 4 coarse granular casts, small diameter, few fat drops and cells adherent; few small and medium round and squamous cells; little mucus.

May 3–4 (twentieth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 6 hyaline casts; 2 fine granular casts, all casts of small diameter, a few containing fat drops; few squamous cells; little mucus.

May 4–5 (twenty-first day of fast).—*Albumin*, least possible trace (very faint reaction). *Sediment*, 4 hyaline casts; 2 fine granular casts, of small diameter; few small and medium round cells; few squamous cells.

May 5–6 (twenty-second day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 7 hyaline casts; 4 coarse granular casts, all casts of small diameter; few small round and squamous cells.

May 6–7 (twenty-third day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 7 hyaline casts; 3 coarse granular casts, all casts of small diameter; few small round and squamous cells.

May 7–8 (twenty-fourth day of fast).—*Albumin*, least possible trace (very faint reaction). *Sediment*, 6 hyaline casts; 4 coarse granular casts, all of small diameter; few small and medium round and squamous cells.

May 8–9 (twenty-fifth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 6 hyaline casts; 2 coarse granular casts; all casts of small diameter, occasional fat drops and cells adherent; few small and medium round and squamous cells; some cells slightly fatty; rare spermatozoa, normal in appearance.

May 9–10 (twenty-sixth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 8 hyaline casts; 1 coarse granular cast; all casts of small diameter; occasional fat drops and cells adherent; few small and medium round and squamous cells, some cells slightly fatty; rare spermatozoa, normal in appearance.

May 10–11 (twenty-seventh day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 8 hyaline casts; 1 coarse granular cast; all casts of small diameter, with a few fat drops and cells adherent; rare spermatozoa, normal in appearance; few medium round cells, slightly fatty; few squamous cells.

May 11–12 (twenty-eighth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 6 hyaline casts; 2 coarse granular casts; all casts of small diameter, a few fat drops and cells adherent; numerous spermatozoa, normal in appearance.

May 12–13 (twenty-ninth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 10 hyaline casts, 3 coarse granular casts; all casts of small diameter, few fat drops and numerous cells adherent; few small and medium round cells; few squamous cells; few spermatozoa, normal in appearance.

May 13–14 (thirtieth day of fast).—*Albumin*, slightest possible trace (very faint reaction). *Sediment*, 12 hyaline casts; 1 coarse granular cast; all casts of small diameter, few fat drops and rather numerous cells adherent; few small and medium round cells; few squamous cells; few spermatozoa, normal in appearance.

May 14–15 (thirty-first day of fast).—*Albumin*, slightest possible trace (distinctly more than last examination). *Sediment*, 36 hyaline casts; 2 coarse granular casts; casts of small and large diameter about equal in number; few fat drops and epithelial cells adherent; few small and medium round cells; numerous squamous cells.

May 15–16 (first day after breaking fast).—*Albumin*, slightest possible trace. *Sediment*, 18 hyaline casts; chiefly of small diameter, with a few fat drops and rare epithelial cells adherent; few small and medium round cells; few squamous cells; very many spermatozoa, normal in appearance; many acid sodium-urate crystals.

May 16–17 (second day after breaking fast).—*Albumin*, slightest possible trace. *Sediment*, 2 hyaline casts of small diameter; few small and medium round cells; few squamous cells; little mucus.

May 17–18 (third day after breaking fast).—*Albumin*, slightest possible trace. *Sediment*, 2 hyaline casts; 1 epithelial cast of small diameter; few small and medium round cells; few squamous cells; many spermatozoa, normal in appearance; many calcium-oxalate crystals.

October 19 (five months after breaking fast).—*Albumin*, least possible trace. *Sediment*, 2 hyaline casts of small diameter; few small and medium round cells; occasional neck-of-bladder cells; few squamous cells.

SUMMARY.

The most remarkable change in character of the urine noted during the fast was the appearance of albumin and casts on the fifth day, which persisted throughout. A summary of the results is given in table 43. During the first 24 hours that food was taken, the urine contained sugar[1] and the sediment showed numerous calcium-oxalate crystals.

The sexual system of the subject remained active throughout the entire period of observation. According to his own statements, a seminal emission occurred two nights before the fast began, he had

[1]See p. 292.

TABLE 43.—*Summary of results.*

Day of fast.	Albumin.	Hyaline casts.	Granular casts.	Size of casts.
3d	0	1	0	
4th	0	0	0	
5th	Sl. possible tr.	13	3	Predominating casts large diam.
6th	do	15	2	Do.
7th	do	5	9	Do.
8th	do	4	5	Do.
9th	do	5	5	Do.
10th	do	8	4	Do.
11th	do	4	3	Size diminishing.
12th	do	7	6	Do.
13th	do	15	2	Do.
14th	do	6	2	Do.
15th	do	15	10	Small diameter.
16th	do	14	12	Do.
17th	do	7	2	Do.
18th	do	8	4	Do.
19th	do	8	4	Do.
20th	do	6	2	Do.
21st	do	4	2	Do.
22d	do	7	4	Do.
23d	do	7	3	Do.
24th	do	6	4	Do.
25th	do	6	2	Do.
26th	do	8	1	Do.
27th	do	8	1	Do.
28th	do	6	2	Do.
29th	do	10	3	Do.
30th	do	12	1	Do.
31st	do	36	2	Large and small about equal.
1st food day	do	18	0	Small diameter.
2d food day	do	2	0	Do.
3d food day	do	2	1	Do.
5 months later	do	2	0	

voluptuous dreams without ejaculation on the night of the thirteenth fasting day, and a seminal emission on the night of the fifteenth fasting day. The urinary sediment contained rare spermatozoa on the third, seventh, and ninth fasting days, very numerous spermatozoa on the fifteenth fasting day, rare spermatozoa on the twenty-fourth, twenty-fifth, and twenty-sixth fasting days, numerous spermatozoa on the twenty-seventh, and a few on the twenty-eighth and twenty-ninth days. On the first and third days after breaking the fast, during the period of extreme mental disturbance, numerous spermatozoa were seen. Microscopically the spermatozoa at all times appeared to be normal in size and shape. There was no motility, but in every instance the urine had been standing for some time before the examination was made.[1]

[1]These observations are fully in line with the observations made by Albitsky on fasting rabbits, which exhibited sexual excitement after 28 to 30 days of fasting. (Cited by Pashutin, in a Course of general and experimental pathology, St. Petersburg, 1902, 2, part 1.) He also notes that spermatozoa were frequently found in the urine of starving rabbits. Pashutin likewise cites Manassein, who observed spermatozoa motile in the urine of rabbits even 33 hours after the animals had perished from the want of food, thus indicating the intense persistency of sexual activity.

In striking contrast to these observations are those of Pojarkov (Compt. rend. Soc. Biol., 1913, 74, p. 141), who with two dogs which had fasted three months noted profound influence upon the sexual activity. Indeed, the depression of the sexual activity was so great and so lasting that Pojarkov even suggested that prolonged fasting may result in a bloodless castration.—F. G. B.

THE RESPIRATORY EXCHANGE.

Any study of the respiratory exchange in a living animal is of dual value, for if properly conducted it throws light upon the character of the katabolism and also supplies data for computing by the indirect method the heat-production of the body, thus serving as a control upon the direct calorimetric measurements of the heat-production. In the fasting experiments at Wesleyan University, the measurements of the respiratory exchange and of the heat-production were coincidental throughout the entire period of the fast. This simultaneous determination had certain great advantages, particularly in establishing the fundamental laws of metabolism obtaining in the early stages of inanition. On the other hand, it gave very little opportunity for securing evidence regarding the minimum or basal metabolism of the fasting subject, since a prerequisite of a study of the basal metabolism is a period of absolute muscular repose.

In these earlier fasting experiments, such a period of absolute muscular repose was best secured during the night, when the subject was in bed and supposedly sound asleep, *i. e.*, quietly at rest. The subject went to bed at 11 o'clock and as the experimental periods were all of 2 hours' duration, the period from 1 a. m. to 7 a. m. could reasonably be taken as the time when the subject had a minimum activity. Unfortunately no direct evidence regarding the degree of muscular activity could be obtained. Furthermore, there was no evidence as to whether the subject was asleep the entire time or more or less awake and somewhat restless.

It seemed advisable, therefore, in planning the study of the long fast at the Nutrition Laboratory, so to arrange the experimental technique and routine as to include a series of respiration experiments which would throw definite light upon the character of the katabolism, measured in both long and short periods, and to be able to isolate certain periods in which the subject was perfectly quiet and under the same conditions of muscular activity throughout the entire series of fasting days. The respiratory exchange of the fasting subject was therefore studied in two ways, *i. e.*, by using the bed calorimeter and the so-called "universal respiration apparatus." With the bed calorimeter both the heat-production and the gaseous exchange could be studied throughout the period that the subject remained in the chamber. In the experiments at Wesleyan University the subject remained in the chamber throughout the whole fasting period and the respiratory exchange could be studied in 24-hour periods. In the prolonged fasting experiment at the Nutrition Laboratory, however, the calorimeter periods usually began at 9 or 10 p. m. and continued until 8 a. m. the following day. Thus for 10 or 11 and but rarely for 9 con-

secutive hours, the gaseous metabolism of the subject inside the chamber could be studied. Graphic records of the degree of muscular activity were also secured by a special form of bed.

The possible differences in the degree of sleep and the degree of restlessness and the impossibility of determining the actual periods of wakefulness and sleep made it seem undesirable to rely wholly upon the determinations of the respiratory exchange made by this method for a comparison of the metabolism as the fast progressed. Consequently each morning, at the conclusion of the night experiment, the respiratory exchange alone was studied for two or three experimental periods by means of the universal respiration apparatus. With this apparatus it was possible to obtain the gaseous metabolism for several 15-minute periods in which the subject lay perfectly quiet and awake, thus giving material for comparison for each day of the fasting period. The element of uncertainty as to the degree of muscular activity and the degree of wakefulness or sleep was by this method entirely eliminated. With both forms of apparatus the respiratory quotient could be accurately determined, so that a mutual control was obtained on the accuracy of the two methods of determining the respiratory exchange.

APPARATUS AND METHODS USED IN THE CALORIMETER EXPERIMENTS.

It is unnecessary to enter into the details of the construction and the technique of using the respiration calorimeter or of the methods of calculating the results obtained with it, as these have been fully explained elsewhere.[1] Since the publication of this description, however, a number of minor though important changes have been made in the apparatus, and hence it seems desirable to discuss them here somewhat at length, so that the complete technique used in these experiments may be available. Although the fundamental principle involved in the determination of the respiratory exchange has not been altered in the slightest degree, our accumulated experience enabled us to develop a technique to meet the special conditions of the fasting experiment which not only facilitated the manipulation of the apparatus but also gave greater accuracy.

ABSORPTION OF WATER-VAPOR AND CARBON DIOXIDE.

According to the usual arrangement of the absorbing system of this apparatus, large porcelain vessels of special form, made by the Royal Berlin Porcelain Works of Berlin, Germany, are used to hold the sulphuric acid for absorbing the water from the air-current, and silver-plated brass cans for holding the soda-lime for absorbing the carbon dioxide. Both of these containers weigh considerable and when the amount of water or carbon dioxide absorbed is 20 to 30 grams, the balance on which they are weighed (which is accurate to about 0.05 gram) is sufficiently exact. On the other hand, when small amounts of

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. 123, 1910.

water or carbon dioxide are to be determined, as for example 10 grams or less, these vessels are too large.

In the earlier part of the fasting experiment, the calorimeter experiments were usually subdivided into three periods, so that the amount of carbon dioxide to be weighed represented that produced in about 3 hours, or approximately 45 to 60 grams. Toward the end of the fasting period it seemed desirable to obtain more definite information regarding the progress of the metabolism throughout the night and hence an attempt was made to secure shorter periods. On one night (May 4–5) the periods were but 1 hour long; under these circumstances only about 11 grams of carbon dioxide were absorbed in each period. It was necessary, therefore, to have some form of absorbing vessel which would weigh considerably less than the usual containers, as the error in weighing might make a measurable difference in the results. We accordingly replaced the large vessels with soda-lime bottles and glass sulphuric-acid containers, *i. e.*, "Williams bottles," similar to those used in the absorbing circuit of the respiration apparatus, and from that time divided the calorimeter experiments into relatively short periods throughout the night, weighing the water and carbon dioxide in these smaller and more accurately weighed containers. A complete description of the glass soda-lime bottle and the Williams bottle is given elsewhere.[1] Soda-lime was used as the absorbent for carbon dioxide throughout the whole fasting experiment, for although at the time the description of the respiration calorimeter was published experiments were being made with potash-lime, subsequent experience has convinced us that, as yet, the original form of soda-lime has not been improved upon.

ANALYSIS OF CHAMBER AIR AT THE END OF PERIODS.

While it was desirable to obtain as short and as many periods as possible in the night calorimeter experiments, it naturally became difficult to arrange the routine so as to secure the largest number of periods without decreasing the accuracy and overtaxing the strength of the assistants, especially as a continuous metabolism experiment of 35 to 40 days was quite outside of our experience. With three periods in each experiment, as was at first planned, it was possible to arrange the program so that a trained observer with two responsible assistants could readily carry out the routine of a calorimeter experiment. One of the difficult parts of the program was to make provision for the analysis of the air residual in the chamber at the end of each period. It had been our custom to do this by deflecting a certain volume of the air from the outgoing air-current through a series of U-tubes containing soda-lime, and pumice stone and sulphuric acid respectively, which absorbed the carbon dioxide and water-vapor from the air. The air

[1]Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 166. See, also, figure 39, p. 316, of this publication, for a diagrammatic representation of these bottles.

was then passed through a calibrated Bohr gas-meter and returned to the system. By this method the amount of carbon dioxide and water-vapor in the air residual in the chamber at the end of the period could be readily computed. This manipulation of U-tubes, reading of gas-meter, barometer, and temperature, all of which was checked by an independent observer according to our usual procedure, made an added complex at the end of each experimental period, which of itself formed a considerable part of the routine. Some simpler method for obtaining data regarding the composition of the air inside the chamber was therefore sought.

Since the publication of the description of the calorimeter, it has been our good fortune to become thoroughly familiar with the very ingenious and accurate gas-analysis apparatus of Sondén of Stockholm, which was used in a research on the composition of outdoor air carried out at the Nutrition Laboratory.[1] This apparatus was employed in the fasting experiment for determining the carbon-dioxide content of the air in the calorimeter chamber. By means of a system of previously dried gas-sampling tubes, samples of the air could readily be taken in a few seconds at the end of each experimental period. The carbon dioxide in these samples of air could then be determined on the Sondén apparatus the next morning by a skilled assistant.

Unfortunately, while ideal determinations of the carbon dioxide could be obtained by this method, it is no less important to know the volume of water-vapor residual in the chamber at the end of the period, and the accurate determination of this factor has been one of our most perplexing problems. With the U-tube system previously described very satisfactory results could be obtained, but with the substitution of the gas sampling and the subsequent determination of the carbon dioxide on a Sondén apparatus, it was necessary to find some method of determining the exact amounts of the water-vapor in the air. It is obviously impossible to take a sample of air, even over mercury, and retain the water-content for any length of time, as it would either be deposited upon the glass tube or so affected that no accurate analysis could be made. Furthermore, for analysis by the ordinary gravimetric method a sufficient volume of air could not be so stored. We therefore began experimenting with a delicate wet- and dry-bulb psychrometer.

Two mercury thermometers, graduated in 0.01° C., were placed in the air-current, one of the thermometers having a moistened strip of linen wrapped around the bulb. The depression of the wet bulb was carefully noted and by comparing the observations thus obtained with results secured by the U-tube method and particularly with the unique and extremely accurate hygrometer of Sondén,[2] it was found that

[1]Benedict, Carnegie Inst. Wash. Pub. 166, 1912, p. 75.

[2]Sondén, Bihang till K. Svenska Vet.-Akad. Handlingar, 1891, **17**, p. 3; see also Meteorologische Zeitschr., 1892, p. 81.

concordant results could be obtained. Hence, to secure records of the water-vapor in the residual air, it was only necessary to place this psychrometer in the air-current inside the respiration chamber. It was so arranged that the air leaving the chamber came through a pipe opening at the rear and extending along the bottom to the front of the chamber near the glass window. The air passed over the dry bulb of the psychrometer and from there over the wet bulb, and then directly to the blower outside. It was therefore possible for the observer on the outside to read both mercury thermometers through the glass front of the calorimeter chamber; readings to 0.01° C. could ordinarily be relied upon. By means of psychrometric tables, the amount of water-vapor residual in the chamber could be very readily computed. It is thus apparent that by reading the psychrometer and taking a single sample of the air in the chamber and subsequently analyzing it, it was possible to obtain information regarding the content of water-vapor and carbon dioxide in the chamber air at the end of each period with a minimum utilization of the assistant's time during the night.

The psychrometer is at present used in this laboratory for short experiments with babies and small animals in which respiration chambers are employed. Having tested this method of determining the water-vapor by two other methods, we felt justified in employing it in the long calorimeter experiments, especially as it requires only the reading of the two thermometers by the assistant at the end of each period. To use the psychrometer successfully, it is necessary that the air should pass rapidly over the bulbs of the thermometers. Care should also be taken that the fabric about the wet-bulb thermometer is kept moist, as in long experiments of 10 or 12 hours it occasionally becomes dry, so that false readings are obtained.

It is obvious that no one of these methods, *i. e.*, the sulphuric acid-pumice stone, the Sondén hygrometer, or the psychrometer, gives the true value for the water-vapor inside the chamber, as they measure only the water-vapor in the outgoing air, and there is certainly an area about the ingoing air pipe (where the air is entering absolutely free from water-vapor) which is of a much lower water-content, notwithstanding the fact that the air is fairly well circulated inside the chamber by means of an electric fan. It should be considered, however, that the values obtained at the beginning and end of each period are for comparison only and we deal here with differences rather than with absolute amounts.

This change in methods was particularly advantageous for the determination of the residual carbon dioxide. When U-tubes are used, it is necessary to pass 10 liters of air through them in order to secure a weighable amount of carbon dioxide. For doing this in a relatively short time, such as 3 minutes, a ventilation through the U-tubes of

about 3½ liters per minute is required and the use of fairly large U-tubes, each weighing about 80 to 90 grams. A combination of one soda-lime U-tube followed by a pumice-stone sulphuric acid U-tube weighs not far from 160 to 180 or even 190 grams, while the amount of carbon dioxide to be weighed is sometimes no more than 60 milligrams. When experimenting with a man awake or doing severe muscular work, the method is perfectly satisfactory, but when experimenting with a man as emaciated as our fasting subject, with a minimum metabolism, and producing only a small amount of carbon dioxide per hour, it is obvious that the residual carbon dioxide in the chamber would be low and it would be difficult to obtain very accurate determinations under these conditions. With the Sondén gas-analysis apparatus, on the contrary, it was possible to determine 0.5 per cent of carbon dioxide to the third significant figure with great accuracy. The advantage of thus obtaining a more delicate determination of the carbon dioxide and at the same time decreasing the work required of an assistant during the long night period made it desirable to introduce the method by which the sampling pipette with subsequent analyses could be used to determine the carbon dioxide and the wet- and dry-bulb psychrometer for determining the water-vapor. The sampling tubes were collected each morning after the night experiment was over, and the analyses made on the Sondén apparatus by Miss Alice Johnson, whose technical skill in the use of this apparatus was well attested in the research on the composition of outdoor air previously referred to.

TENSION EQUALIZER.

The rubber bathing cap used as a tension equalizer in the earlier form of respiration calorimeter has been replaced by a spirometer which was first designed for the universal respiration apparatus. A brief description of this spirometer with diagram (figure 40) is given on page 318, but a more detailed description may be found in an earlier publication.[1]

The spirometer is attached directly to the side of the respiration chamber and thereby becomes a part of the chamber volume, thus providing for fluctuations in the volume of the air inside the apparatus. As the carbon dioxide is absorbed by the soda-lime and the oxygen is used by the man inside the calorimeter, the total volume of the air inside the chamber gradually decreases. Accordingly the spirometer bell slowly falls until a certain point is reached where an electric contact (not shown in figure 40) is made and oxygen thereby automatically admitted by means of an electric valve attached to the oxygen cylinder. When sufficient oxygen is admitted to raise the bell and break the contact, the flow of oxygen is automatically stopped; in this way the supply of oxygen is under continuous control.

[1]Benedict, Deutsch. Archiv f. klin. Med., 1912, 107, p. 172. See also Benedict and Talbot. Carnegie Inst. Wash. Pub. 201, 1914, p. 43.

In the fasting experiment, use was made of this spirometer to indicate the constancy of conditions. For example, if the oxygen supply was completely shut off for 5 or 6 minutes before the probable end of an experimental period and the pointer on the spirometer bell was allowed to rest against the smoked-paper drum, a regular rising curve would be drawn on the rotating drum, thus indicating the slow, steady fall of the spirometer bell. If the subject made a muscular movement, as in turning over, or for any reason there was an irregularity in the curve, it was obvious that there was a sudden expansion or contraction of the air in the chamber which could not be corrected for by the measurement of the temperature and barometer. Consequently, if such an irregularity in the line occurred during the last 5 minutes of the experimental period, the length of the period was extended until a regular curve could be secured. This was most helpful in many instances. Specimen curves are given in figure 36 showing this method of utilizing the spirometer. It is of course necessary to note the exact height of the spirometer at the moment the period is ended. This is done by reading the position of the pointer attached to the counterpoise of the spirometer as it travels over a millimeter scale.

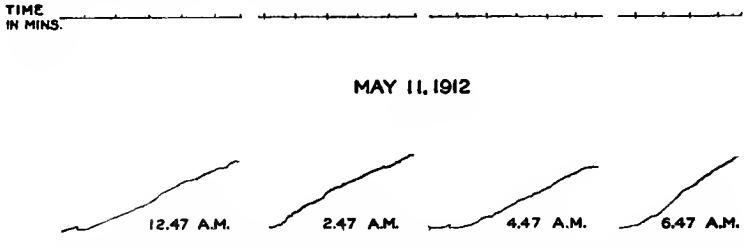


FIG. 36.—Specimen records of change in volume of the spirometer on the bed calorimeter during last 5 minutes of periods in experiment with L.

ARGON IN OXYGEN FROM LIQUID AIR.

In recent years we have used the nearly pure oxygen obtained from liquid air by the Linde Air Products Company. At first we were unaware of the fact that the residual gas was not, as commonly considered, all nitrogen with an atomic weight of 14, but consisted in large part of argon with an atomic weight of 40. Hence it has been necessary to emphasize the fact that in computing either the volume of oxygen admitted from a cylinder or in calibrating a gas-meter by the method of weighing the oxygen,[1] the composition of this residual gas should be taken into consideration, as otherwise an appreciable error in the percentage of oxygen may easily occur. Thus, in a series of observations carried out on diabetics[2] and likewise another series on muscular work,[3]

[1]Benedict, Physical Review, 1906, **22**, p. 294.
[2]Benedict and Joslin, Deutsch. Archiv f. klin. Med., 1913, **111**, p. 350.
[3]Benedict and Cathcart, Carnegie Inst. Wash. Pub. 187, 1913, p. 74.

it was found that this correction for argon in place of nitrogen altered the oxygen consumption about 1 per cent and consequently altered the values for the respiratory quotient by a like amount.

GRAPHIC REGISTRATION OF DEGREE OF MUSCULAR REPOSE OF SUBJECT INSIDE THE RESPIRATION CALORIMETER.

The intimate relationship exhibited between the degree of muscular repose and the total metabolism compelled us to make sure, at the beginning of the fasting experiment, that the measurements of the metabolism made with this subject from time to time were comparable so far as muscular repose was concerned. Great care was taken to secure experimental periods when the subject was perfectly quiet and awake, and likewise when he was asleep. All this care would have been of no avail, however, if we had not been able to secure periods of like muscular repose or activity. If, for example, the subject had been noticeably restless on the first few nights of the period of prolonged fasting and on the last nights was especially quiet, the decrease in the metabolism could not be shown to have been due to the influence of the fast, but might have been due to the differences in the degree of muscular repose. While statements could be secured from the subject or from observers as to how well the subject slept or how quietly he lay, no reliance could be placed upon them, as our experience has been that such observations are usually untrustworthy. Hence we made use of a method of graphic registration, which succeeded the ocular observations of the muscular activity used in connection with the experiments in Wesleyan University, and likewise had its own development later in this laboratory. In the earlier experiments we placed about the body of the subject either one or two tube pneumographs in such a position that not only was the respiration-rate recorded, but likewise any muscular movement of the body.[1] When the subject was lying down, it was found that these pneumographs became irksome if worn for several hours. In the experiments with diabetics,[2] the use of the pneumograph was found to be satisfactory, as the apparatus was rarely worn continuously for more than 3 hours. In the fasting experiment, however, it would be necessary for the subject to wear the pneumograph for some 12 or 13 hours each night, and as the degree of emaciation became greater it was quite possible that the discomfort might be such as to disturb his sleep if not, indeed, cause pain; also, that the subject might turn over during the night and cramp the transmission tube in such a way as to prevent proper registration.

Previous experiences in this laboratory with a suspended cage or crib for dogs or infants led us to apply the same principle for devising a special form of bed for use in experiments with the universal respira-

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 10.
[2]Benedict and Joslin, Carnegie Inst. Wash. Pub. 136, 1910, p. 22.

tion apparatus in which the subject lies upon a couch. This bed was so suspended that the slightest change in the center of gravity of the body, such as moving the hand or the foot, would alter the tension on the spring inside a pneumograph and thus transmit the movement to a tambour and kymograph. By this means the least muscular activity would be recorded. With the suspended crib used in experiments with infants, experience has shown that the best point of support was at the

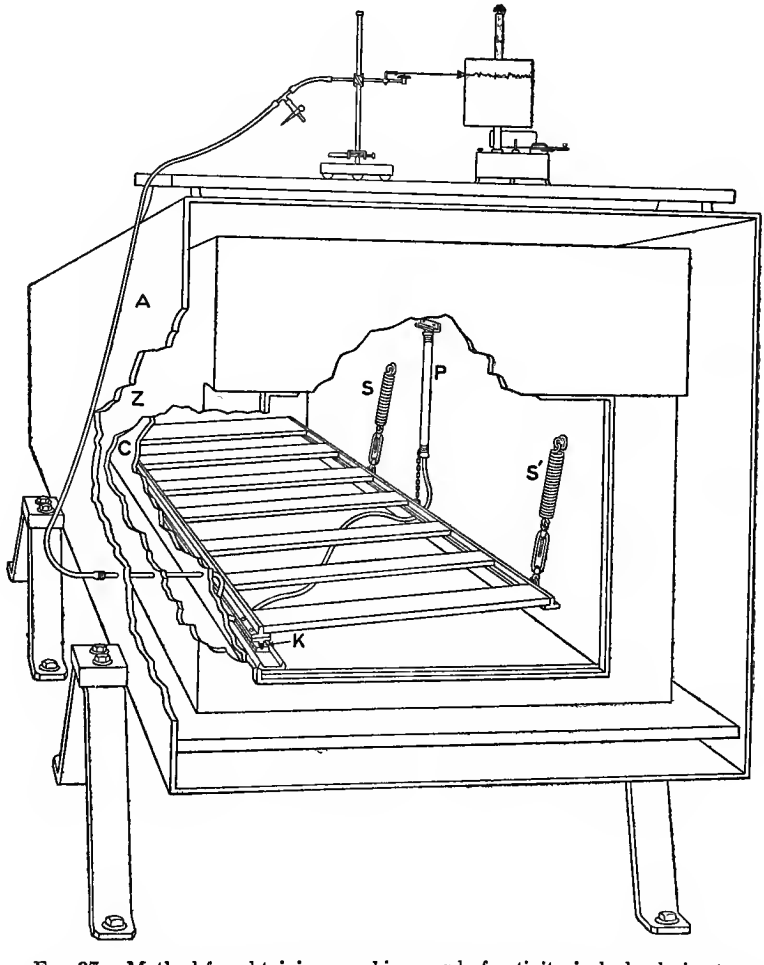


FIG. 37.—Method for obtaining graphic record of activity in bed calorimeter.

The subject lies on the bed on the framework inside the calorimeter. One side of the frame rests on a knife-edge, K; the other side is supported by two stout spiral springs, S and S'. Any change in the tension on the springs likewise affects the tension on the pneumograph, P, thus altering the tension of the air in the pneumograph. By means of a rubber tube and a metal pipe passing through the copper wall, C, zinc wall, Z, and asbestos wall, A, of the calorimeter, the lower end of the pneumograph communicates with a tambour which writes on the kymograph placed above the calorimeter. Any lateral change in the center of gravity of the body instantly produces a movement of the pointer on the kymograph.

foot of the crib, the spring being placed at the head. With adults, however, we soon found that the major movements were lateral rather than lengthwise of the body and the supports and springs were accordingly placed at the sides of the bed instead of at the head and foot.

This bed, when used in the calorimeter chamber, was supported at one side on two frictionless steel points and at the other by two stout spiral springs which could be adjusted by turnbuckles to bring the bed to a level position. Obviously any change in the center of gravity of the body altered the tension upon the two supporting springs, which were therefore elongated or shortened. When the pneumograph was attached to the bed, the same force producing the elongation or contraction of the springs affected the pneumograph. The change in the tension of the air inside the pneumograph was transmitted by the usual method, *i. e.*, by means of a metal tube passing through the walls of the chamber and subsequently by a rubber tube connecting with the tambour, writing-point, and kymograph. The method of obtaining this graphic registration of the muscular activity is shown in figure 37.

In this figure the open end of the bed calorimeter is shown in perspective and in a somewhat schematic way. C, Z, and A represent respectively the inner copper wall of the chamber, the zinc middle wall, and the outer asbestos wall. The framework of the bed is seen at the bottom of the calorimeter chamber with the left-hand edge resting on the steel support, K. The two spiral springs, S and S′, each provided with a turnbuckle, are attached at the upper end to the wall of the calorimeter chamber and at the lower end to the right-hand edge of the bed. Midway between the springs is attached a pneumograph, P, the upper end of which is attached to the wall of the calorimeter chamber.

The subject, lying upon an air mattress which is in turn resting upon a long plate of galvanized iron, is slid on to the bed framework feet first. As the weight of the body falls upon the framework, the springs, S and S′, become extended, the adjustment necessary to secure perfect leveling of the bed being made by means of the turnbuckles. If the subject turns during the night, a greater tension is put upon the springs, S and S′, and the pneumograph, P, is elongated.[1] The air in the tube connecting the pneumograph with the outside of the chamber is thus somewhat rarefied and the tambour pointer sinks, thus producing a depression in the line on the kymograph drum.

[1]For the benefit of other workers in this field, it is of interest to record here the recent experience of Dr. Paul Roth, of Battle Creek, Michigan. In recording the body-movements of men or women lying on beds, he replaced the pneumograph with a small Politzer bulb, so adjusted as to be somewhat compressed by the bed-frame. The bulb was connected to the tambour and kymograph. Preliminary tests made in the Nutrition Laboratory with the Politzer bulb arrangement have shown that the results of the variation in pressure on the bulb by variation in muscular activity are most satisfactory, not only with adults but also with small animals—a fact of special interest in connection with the research on infants. Two serious objections to the pneumograph, *i. e.*, the danger of leaks through the rubber and the difficulty of renewing the rubber, are thus obviated by the use of this bulb. A flexible rubber bulb of small size is best used.

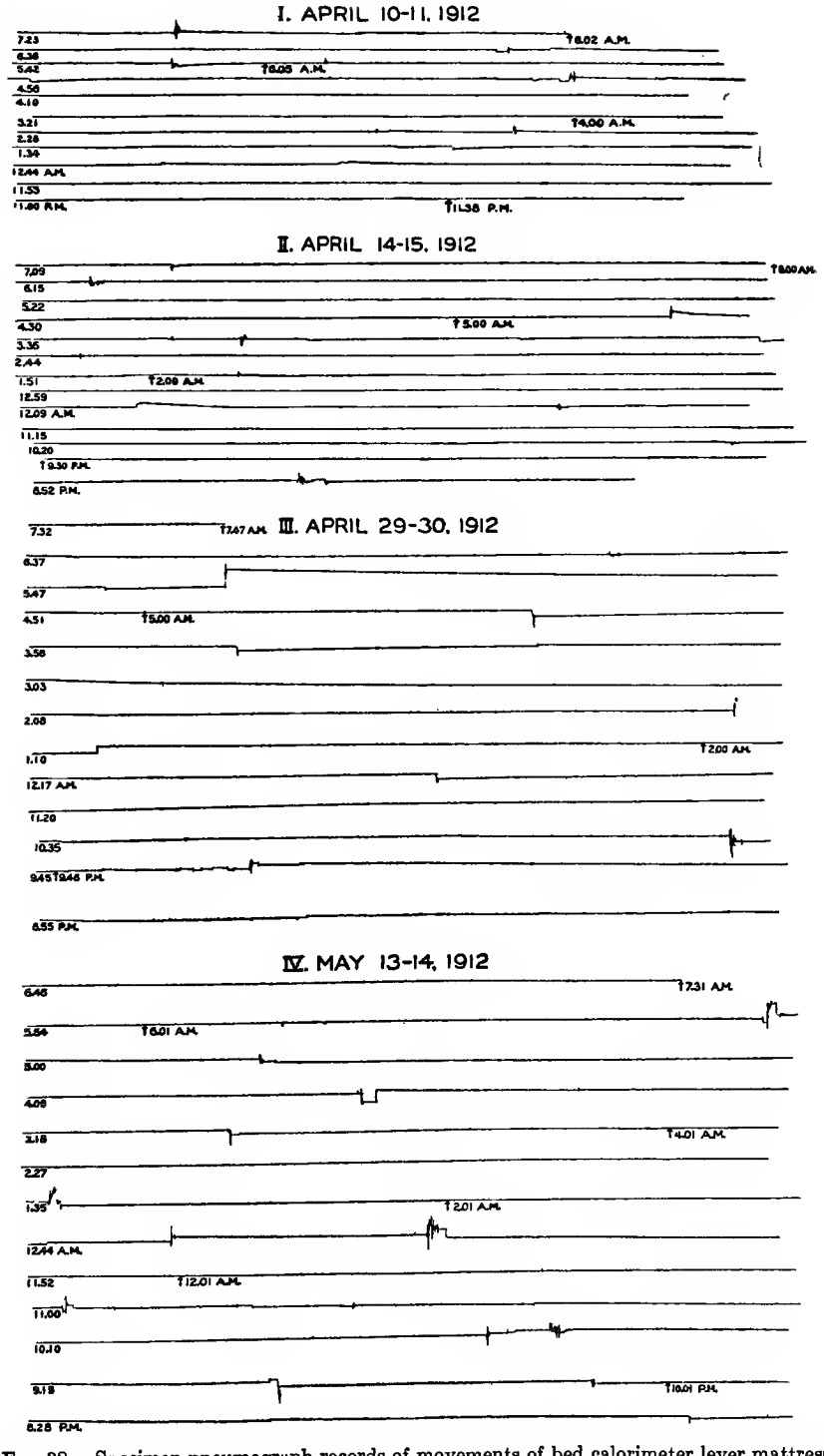


FIG. 38.—Specimen pneumograph records of movements of bed calorimeter lever mattress support in night experiments with L.

The apparatus is extremely sensitive and shows plainly such minor muscular motions as movements of the hand or arm to one side or, indeed, the twisting of the feet. Throughout his whole stay in the laboratory, L. slept on this bed inside the respiration chamber each night and a kymograph record was therefore obtained for the whole period. The drum of the kymograph was usually rotated at such a speed as to give one revolution of 500 mm. per hour.

Although these kymograph records were not secured primarily for publication, four typical records have been arbitrarily selected for reproduction in figure 38. The curve for April 10–11, 1912 (Curve I), which represents the record obtained on the first night which the subject spent inside the chamber, begins at 11 p. m., April 10, and ends at $8^h\ 02^m$ a. m., April 11. For the most part the subject was remarkably quiet, showing no considerable degree of restlessness until about 5 a. m. on April 11.

The curve for April 14–15, 1912 (Curve II) represents the record obtained on the first night of the fasting period. The line here is remarkably regular, showing relatively few major muscular movements. When there is a distinct change in the level of the mark made by the pointer, as is seen at approximately $5^h\ 12^m$ a. m., this is an indication that the subject changed his position, probably turning on his side.

Another curve (Curve III) has been selected from those obtained about the middle of the fasting period, which represents the record for April 29–30, 1912. This also shows a general regularity of line, with occasional indications of changes in position.

The last curve (Curve IV) was obtained on the next to the last night of the fasting period, May 13–14, 1912. Between $12^h\ 45^m$ a. m. and $1^h\ 45^m$ a. m. there was considerable movement for a few moments at two or three different times, but otherwise the record has much the same characteristics as the other curves shown.

From these curves and also from other curves which it is impracticable to reproduce here, we may logically infer that this subject was particularly quiet inside the respiration chamber. While he did not sleep the entire time, yet the kymograph records show that he was for the most part very comfortable inside the chamber—indeed, he repeatedly made the statement that he was very comfortable throughout the night. It is of interest to note that at the hospital he said that the bed there was not so comfortable as the bed inside the calorimeter chamber.[1]

METHODS USED IN EXPERIMENTS WITH THE RESPIRATION APPARATUS.

The universal respiration apparatus, which was used for the respiration experiments throughout the day, is based upon the same principle as the large respiration calorimeters. A great variety of experiments

[1]See page 51.

have been made with it in this laboratory, and its accuracy has been thoroughly tested. Not only men and women have been used as subjects, but, by adding a small chamber, experiments have also been made with infants and small animals. The apparatus has been described in detail elsewhere.[1]

With this apparatus the subject lay quietly on the same bed upon which he slept during the night, the bed being withdrawn from the respiration chamber and placed upon a small framework in the calorimeter laboratory. He was covered with bed clothing and two soft-rubber nose-pieces were inserted in the nostrils, the subject being cautioned to keep his mouth closed. After he had breathed a few minutes through a two-way valve opening into the room, the valve was turned and he began to breathe into a closed volume of air—some 8 or 10 liters—which was kept in motion by a ventilator or blower. As the air left the nostrils of the man, it was carried by the blower to suitable

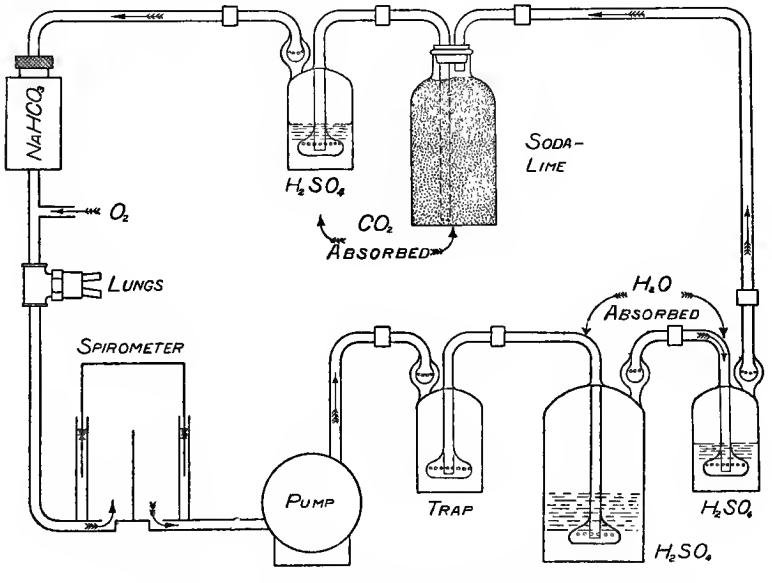


Fig. 39.—Schematic outline of universal respiration apparatus.

The subject, lying upon a couch or bed, breathes either through the two nose-pieces or a mouth-piece into a ventilating current of air, kept in motion by a rotary pump. The moisture in the air is absorbed in two glass vessels containing sulphuric acid, an empty glass vessel serving as a trap to prevent accidental back suction of acid. The dried air then passes through soda-lime and again through sulphuric acid in a special form of bottle and finally through a can containing sodium bicarbonate to free the air of any traces of acid vapor. Oxygen is introduced as desired. The air is then ready to be inhaled by the lungs. As the air leaves the lungs, the changes in the volume of the confined air are recorded on the spirometer, which moves freely up and down with each inspiration and expiration. The change in weight of the soda-lime vessel and its accompanying sulphuric-acid bottle gives the weight of the carbon dioxide produced. The weight of the oxygen is obtained either by noting the loss in weight of the cylinder of the gas or measuring the gas carefully admitted through a meter.

[1]Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 156.

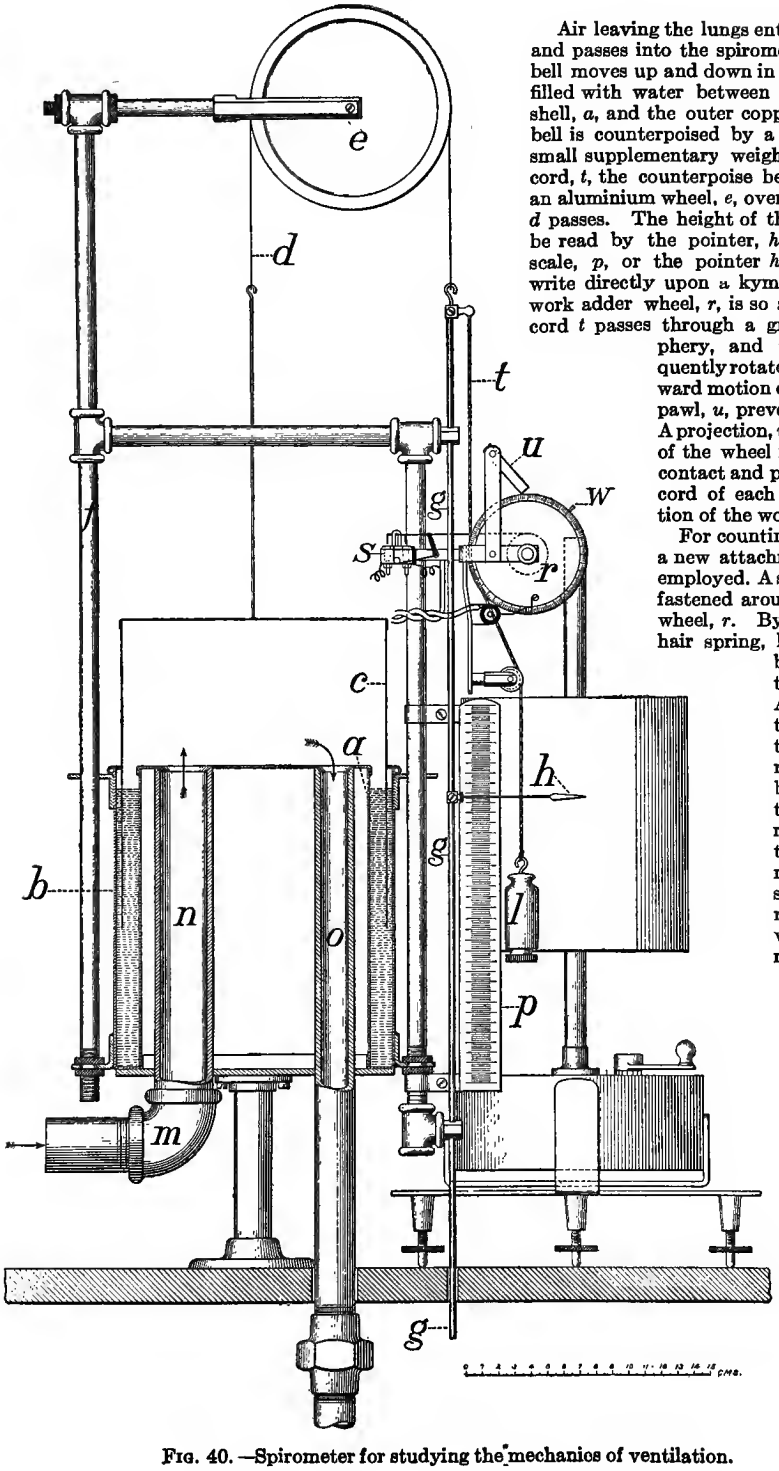
containers in which the water and carbon dioxide were absorbed; oxygen was next added from a cylinder of weighed gas or through a calibrated meter to replace that used by the man; the air was then returned to the subject. The amount of carbon dioxide excreted was obtained from the changes in weight of the absorbers and the amount of oxygen consumed from the record of the oxygen admitted to the air-current. Experiments could be made with this apparatus with periods as short as 15 minutes. The general scheme of the respiration apparatus is shown in figure 39.

In this apparatus provision has been made for fluctuations in the volume by attaching a tension equalizer. In the earlier forms of the respiration apparatus, a rubber bathing cap was used as a tension equalizer, but more recently this has been replaced by a spirometer. This spirometer not only provides for the fluctuations in the volume of air, but has been utilized for recording the character of the respiration, as has already been noted in a previous section of this publication. (See page 158.) It has also been used with the bed calorimeter for indicating the constancy of conditions. (See page 310.) The details of the spirometer are shown in figure 40.

With each inspiration and expiration, the thin copper bell, *c*, of the spirometer falls and rises in the annular space between the copper walls, *a* and *b*, this space being filled with water. To the counterweight rod, *g*, *g*, *g*, is attached a pointer, *h*, which writes on the smoked-paper surface of the kymograph drum. A wheel, *r*, with a milled edge, is rotated by each upward movement of the cord, *t*, which rests in a groove in the edge of the wheel, the pawl, *u*, preventing any backward movement of the wheel. By means of a platinum contact on the periphery of *r*, each complete revolution of the wheel may be recorded. An explanation of the use made of the records obtained with this spirometer and a series of typical kymograph curves are found on pages 158 to 160.

The respiration apparatus was used regularly each morning of the fast for an experiment immediately following the night's sojourn in the bed calorimeter. The subject, lying upon his bed, was transferred directly from the calorimeter chamber to the respiration apparatus. He then turned upon his side and urinated without rising and the respiration experiment was begun shortly afterwards. In the latter part of the fast, the apparatus was used for a respiration experiment each evening about an hour before the subject entered the calorimeter. At irregular intervals throughout the fast the respiratory exchange was also studied with the respiration apparatus, while the subject was sitting quietly in a chair or writing steadily, as he did much of the time. The apparatus was likewise used for experiments in which the subject breathed an oxygen-rich atmosphere while lying upon the couch.

All of these experiments included two or three periods of approximately 15 minutes each, in which records of the degree of muscular



Air leaving the lungs enters the pipe, *m n*, and passes into the spirometer bell, *c*. This bell moves up and down in the annular space filled with water between the inner copper shell, *a*, and the outer copper shell, *b*. The bell is counterpoised by a rod, *g g g*, and a small supplementary weight, *l*, attached to a cord, *t*, the counterpoise being supported by an aluminium wheel, *e*, over which the thread *d* passes. The height of the spirometer can be read by the pointer, *h*, on a millimeter scale, *p*, or the pointer *h* can be made to write directly upon a kymograph drum. A work adder wheel, *r*, is so attached that the cord *t* passes through a groove in its periphery, and the wheel consequently rotates with each downward motion of the bell *c*. The pawl, *u*, prevents back motion. A projection, *w*, in the periphery of the wheel makes an electric contact and permits graphic record of each complete revolution of the work adder wheel.

For counting the respirations a new attachment, *s*, has been employed. A steel wire is loosely fastened around the hub of the wheel, *r*. By means of a light hair spring, lateral tension is brought against the movable rod, *g*. As the rod ascends, the steel wire rotates out of the mercury cup, breaking the electric contact; as the rod moves down, the contact is made. A small stop above the mercury cup prevents the wire from rising too far.

FIG. 40.—Spirometer for studying the mechanics of ventilation.

repose were obtained by means of the special form of suspended bed, and the pulse-rate was regularly observed.[1] The subject L. adjusted himself very readily to this apparatus, finding it not at all uncomfortable. Indeed, on one or two occasions he expressed his enjoyment of the soothing sensation produced by the slight sound of the blower. He seemed to be in no wise affected by the apparatus and to him apparently the respiration experiment was but a slight incident in the day's program. These experiments were all personally supervised by Mr. Carpenter, who found this subject more nearly ideal than any subject he had ever studied, as the man could be relied upon to keep absolutely quiet throughout the whole period. The record of the degree of muscular repose also shows this fact,[2] and it is especially advantageous to have this assurance that, as the fast progressed, whatever disturbance in the total metabolism is observed as a result of varying body position or the inhalation of oxygen-rich atmospheres, it certainly was not complicated by extraneous muscular activity.

Aside from the value of being able to study the respiratory exchange under the different conditions of waking, sitting, and writing, the universal respiration apparatus offered special advantages for likewise studying the mechanics of respiration, including the respiration-rate, the character and volume of each respiration, and the ventilation of the lungs per minute, and for indicating in general any abnormality in the mechanics of respiration. It was also possible to determine the alveolar air of the subject in these respiration experiments.[3]

As both the morning and evening series of respiration experiments were made under the same conditions of muscular repose and with the subject awake, the results obtained are perfectly comparable, so that they give excellent data for drawing sharp conclusions as to the influence of prolonged fasting upon the general metabolism. Furthermore, since two wholly independent series of respiration experiments were obtained with different apparatus and at a different time of day, the individual periods of both the experiments with the bed calorimeter and the respiration apparatus are made doubly valuable by this check. It is important to bear in mind, however, that the experiments with the universal respiration apparatus gave no evidence regarding either the water-vapor exhaled from the lungs and skin or the cutaneous respiration. As Magnus-Levy has pointed out,[4] there is a greater amount of carbon dioxide excreted through the skin than of oxygen absorbed, so that there is a tendency for the respiratory quotient to be affected by about 0.01. When, therefore, a respiratory quotient of 0.73 is obtained with a subject in the respiration chamber of the calorimeter, a respiratory

[1] See pp. 311, 99, and 110.
[2] See figure 22 on page 159.
[3] See discussion of these results on pages 168 to 181.
[4] Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, 1896, 1, p. 218.

quotient of but 0.72 would, under like conditions, be obtained with the respiration apparatus. On the other hand, the experiments made with the universal respiration apparatus are extremely helpful as a general index of the respiratory exchange from which the calorimetry can be computed by the indirect method. We considered it of importance to make a special effort to secure experiments of short duration, as the technique of the experiments made by Luciani on Succi have been adversely criticized by Zuntz and the experiments made by Zuntz and his co-workers on the fasters Breithaupt and Cetti in Berlin were certainly complicated by colic and a head cold. Moreover, it is not unreasonable to suppose that the technique in thirty years has been materially improved.

STUDIES WITH THE BED CALORIMETER.

ATMOSPHERIC CONDITIONS INSIDE THE CHAMBER.

Prior to a consideration of the results of the study of the gaseous exchange inside the bed calorimeter, it is advisable to note the exact conditions of ventilation, temperature, and particularly relative humidity under which this subject was living in the chamber. The respiration calorimeter was ventilated at a rate of approximately 40 liters per minute, or roughly speaking, 2,400 liters per hour. Since the volume of the chamber was not far from 800 liters, theoretically the air would be replaced inside the chamber three times each hour. The cooling arrangement prevented an abnormal rise in the temperature, and a study of the relative humidity under these conditions presents certain features of interest. Since the air is dried over sulphuric acid before it is returned to the calorimeter, it enters the respiration chamber absolutely water-free and consequently the only sources of water-vapor inside the chamber are the lungs and the skin of the man. The ventilation of the chamber per hour, the amount of water vaporized per hour, the average temperature of the calorimeter chamber, and the relative humidity of the air are given in table 44.

Daily tests, in which the number of revolutions of the blower are recorded by an automatic counter, have shown that in general 210 revolutions of the blower correspond to a ventilation of 1 cubic foot or 28.315 liters of air. The total ventilation may therefore be obtained by dividing the number of revolutions by this factor and multiplying by 28.315. As a matter of fact, the number of revolutions per cubic foot of air was determined each day and this variable used in the calculation. From the length of period as given in table 44, the ventilation per hour was readily found.

All of the water-vapor removed from the chamber was absorbed by sulphuric acid as the ventilating current passed through the absorbing system. The total amount was corrected for the small amount of

water vaporized from the wet bulb of the psychrometer, and the amount per hour found in the usual way.

The average calorimeter temperature was secured by means of a series of resistance thermometers. The relative humidity was calculated from the amount of water vaporized per liter of ventilation and the number of milligrams of water-vapor in one liter of air saturated at the calorimeter temperature.

The rate of ventilation and the rate of carbon-dioxide production were such that the usual proportion of carbon dioxide residual in the

TABLE 44.—*Ventilation of chamber and relative humidity during experiments with L. in bed calorimeter at night.*

Date.	Day of fast.	Period.	Ventilation per hour. A	Water vaporized per hour. B	Average temperature of the chamber. C	Relative humidity. D
1912.			*liters.*	*gm.*	*°C.*	*p. ct.*
Apr. 10–11	.....	11h 38m p.m. to 8h 02m a.m.	2253	25.3	21.32	62
11–12	.....	10 13 p.m. 8 00 a.m.	2472	26.3	20.17	62
12–13	.....	11 13 p.m. 8 00 a.m.	2473	26.6	21.28	59
13–14	.....	11 09 p.m. 8 00 a.m.	2454	27.1	20.72	63
14–15	1st...	9 30 p.m. 8 00 a.m.	2474	22.8	20.77	52
15–16	2d....	9 41 p.m. 8 00 a.m.	2468	25.6	20.65	59
16–17	3d....	9 22 p.m. 7 55 a.m.	2469	28.7	21.41	63
17–18	4th...	8 58 p.m. 8 00 a.m.	2369	22.8	20.77	54
18–19	5th...	9 57 p.m. 7 50 a.m.	2328	21.1	21.19	50
19–20	6th...	9 30 p.m. 8 00 a.m.	2410	19.4	20.09	47
20–21	7th...	9 23 p.m. 7 58 a.m.	2467	18.9	20.76	43
21–22	8th...	9 47 p.m. 7 55 a.m.	2432	19.2	20.37	46
22–23	9th...	9 50 p.m. 8 00 a.m.	2395	21.1	21.28	48
23–24	10th...	9 12 p.m. 7 52 a.m.	2204	17.0	20.82	44
24–25	11th...	9 18 p.m. 8 00 a.m.	2347	18.3	20.91	44
25–26	12th...	9 40 p.m. 7 52 a.m.	2254	17.9	20.75	45
26–27	13th...	9 53 p.m. 5 00 a.m.	2376	18.4	21.16	43
27–28	14th...	10 13 p.m. 8 00 a.m.	2313	17.6	20.58	43
28–29	15th...	9 27 p.m. 7 51 a.m.	2134	13.6	20.08	38
29–30	16th...	9 46 p.m. 7 47 a.m.	2321	15.9	20.08	40
Apr. 30–May 1	17th...	9 29 p.m. 8 00 a.m.	2309	15.6	20.19	39
May 1– 2	18th...	9 15 p.m. 7 50 a.m.	2334	16.0	20.65	39
2– 3	19th...	9 51 p.m. 8 00 a.m.	2307	15.5	20.23	39
3– 4	20th...	9 35 p.m. 7 55 a.m.	2356	15.8	20.57	38
4– 5	21st...	9 31 p.m. 8 01 a.m.	2268	14.6	20.73	38
5– 6	22d....	10 14 p.m. 7 50 a.m.	2212	15.7	20.68	40
6– 7	23d....	9 35 p.m. 7 46 a.m.	2137	16.7	20.77	45
7– 8	24th...	9 34 p.m. 7 50 a.m.	2195	16.5	20.54	44
8– 9	25th...	10 41 p.m. 7 59 a.m.	2205	17.5	20.64	46
9–10	26th...	10 08 p.m. 8 03 a.m.	2309	18.0	20.53	46
10–11	27th...	10 47 p.m. 8 00 a.m.	2243	18.7	20.71	48
11–12	28th...	9 55 p.m. 7 30 a.m.	2312	18.9	21.02	46
12–13	29th...	9 30 p.m. 7 30 a.m.	2318	19.3	21.25	46
13–14	30th...	10 01 p.m. 7 31 a.m.	2257	19.7	21.12	49
14–15	31st...	9 38 p.m. 7 56 a.m.	2395	17.9	21.10	42
16–17	.....	9 54 p.m. 7 54 a.m.	2318	20.0	20.65	50
17–18	.....	11 57 p.m. 5 54 a.m.	2455	23.7	20.46	56

chamber at the end of each experimental period throughout the night was not far from 0.4 per cent by volume or approximately 13 times that of normal air. This percentage of carbon dioxide in the air, and indeed a very much higher percentage, has been shown to be entirely without effect upon persons breathing such an atmosphere,[1] so that it may be stated with perfect confidence that the excess amount of carbon dioxide present in the chamber could in no way have influenced either the respiratory exchange or the heat-production of the subject.

As will be seen from table 44, the ventilation of the chamber averaged not far from 2,200 to 2,300 liters per hour throughout the 31 days of the experiment, the range being from 2,134 liters to 2,474 liters per hour. The hourly vaporization of water had a tendency to decrease as the fast progressed, the largest amount being on the night of the third day of fasting and the smallest on the night of the fifteenth day of fasting. The average temperature of the calorimeter remained for the most part within a few tenths of a degree of the average figure, 20.6° C.

The relative humidity shows an interesting course. Beginning with approximately 60 per cent on the nights following food, it decreased to a minimum level of approximately 39 per cent from the fifteenth to the twenty-first day and thereafter rose gradually to the end of the fast. The variations in the excretion of water-vapor and the cause of the fluctuations in the relative humidity will be discussed in a subsequent section of this publication.[2] The results secured in the measurements of the respiratory exchange inside the bed calorimeter may, therefore, now be considered.

MEASUREMENT OF THE RESPIRATORY EXCHANGE INSIDE THE BED CALORIMETER.

With the bed calorimeter it is possible to determine simultaneously the water vaporized inside the chamber, the carbon dioxide produced, and the oxygen consumed. These determinations were made directly on four nights prior to the fast, on the 31 nights of the fast, and for two nights after the fast. While the greatest emphasis must be laid upon the total amounts measured, the absorbing vessels were changed several times during the night, so that the experiment was usually subdivided into three periods. In the latter part of the fast, the measurements were made in five or six periods, and on two nights, seven and nine periods respectively. It was accordingly possible to compute the carbon-dioxide output, the oxygen intake, and the respiratory quotient for the whole experiment and also for the individual periods, thus giving a control on the measurement of the respiratory exchange.

[1] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. No. 175, 1907, p. 237.
[2] See page 373.

PERIODIC CHANGES IN THE METABOLISM.

The average results for the experimental periods have been plotted in the form of curves for each night that the subject spent inside the respiration chamber. (See figures 41 to 44.) These results are given in cubic centimeters per minute, the scale values on the outside indicating the values for the oxygen consumed, and those on the inside the values for the carbon dioxide produced. The respiratory quotient for each individual period is placed between the oxygen and the carbon-dioxide curves. Thus, on the night of April 10–11, the oxygen intake for the first period averaged 284 c.c. per minute, for the second period

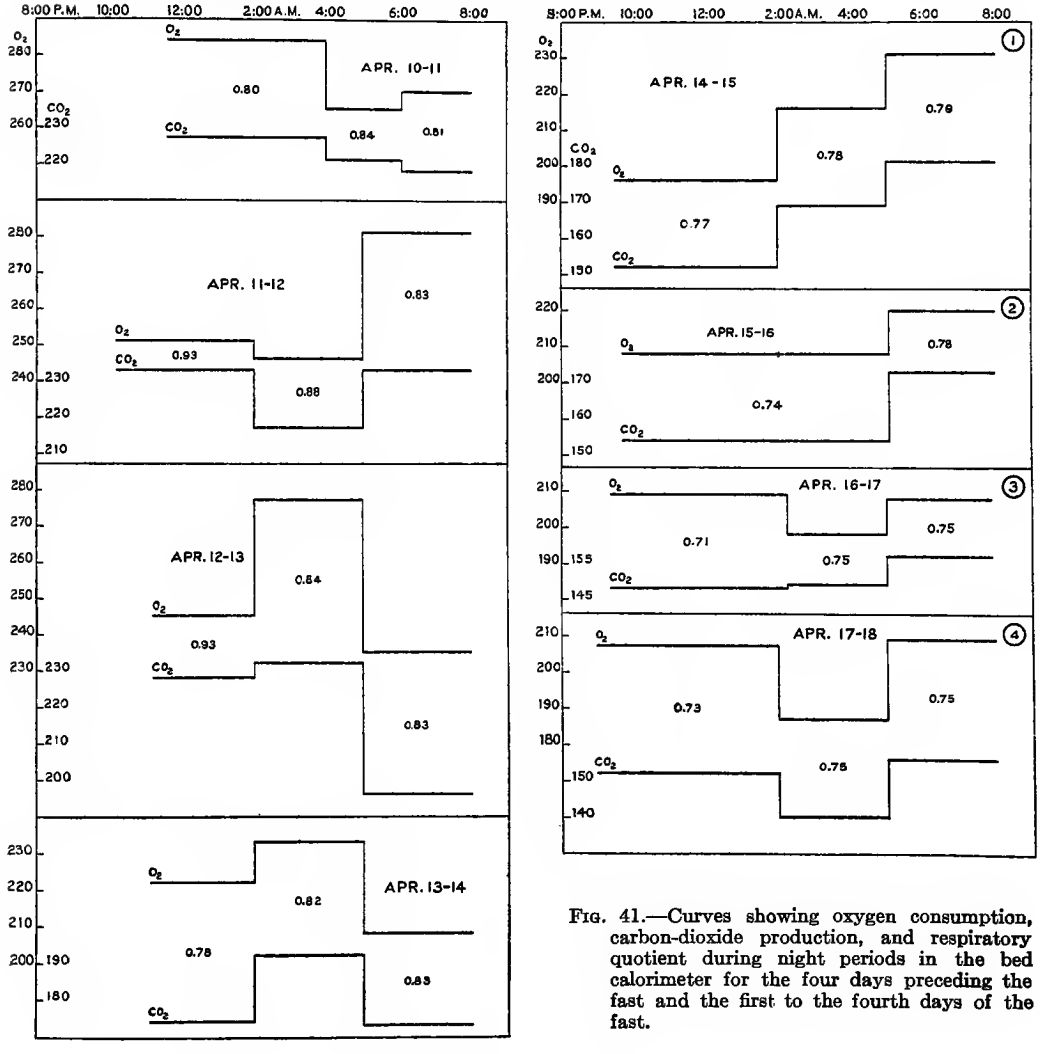


FIG. 41.—Curves showing oxygen consumption, carbon-dioxide production, and respiratory quotient during night periods in the bed calorimeter for the four days preceding the fast and the first to the fourth days of the fast.

265 c.c. per minute, and for the third period 270 c.c. per minute. The carbon-dioxide production for the corresponding periods was respectively 227, 221, and 218 c.c. per minute and the respiratory quotients 0.80, 0.84, and 0.81 respectively.

The subdivision into experimental periods was made in an attempt to secure information regarding the periodic changes throughout the night. But from fundamental factors in the technique of the calorimeter experiments, the longer the experimental periods, the more accurate are the measurements of the carbon-dioxide production and especially of the oxygen consumption; hence by subdividing these total values, a certain degree of accuracy is sacrificed in the measurements, although the average values for the night are unaffected. This may explain certain discrepancies in the respiratory quotient and in the general conformity of the curves for the oxygen and the carbon dioxide.

It will be seen that as a rule the curves for the carbon dioxide and oxygen are essentially parallel, although they are by no means straight

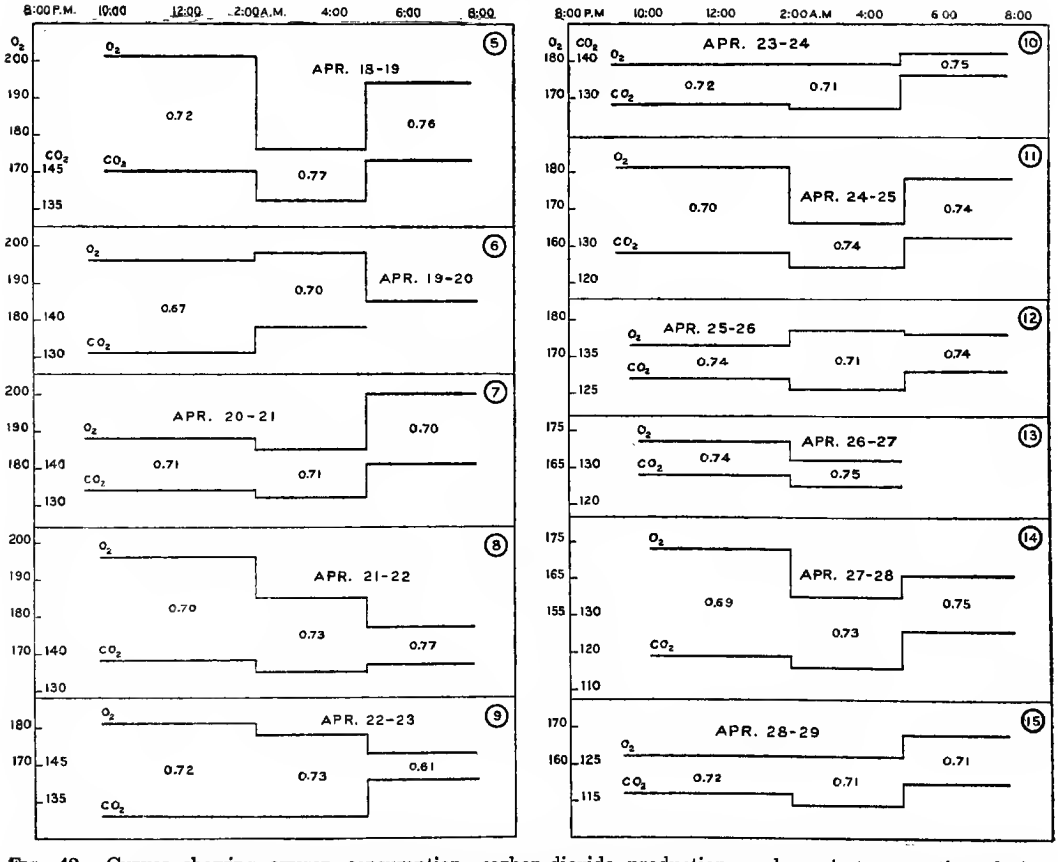


FIG. 42.—Curves showing oxygen consumption, carbon-dioxide production, and respiratory quotient during night periods in the bed calorimeter for the fifth to the fifteenth days of the fast.

lines for the whole experiment. Occasionally, discrepancies are found, as on April 10–11 (the first night of the experiment) when the carbon-dioxide production is higher in the second period than in the last period, while as a matter of fact the oxygen consumption is apparently somewhat lower. This is especially noticeable on April 22–23, when the carbon-dioxide production in the last period increased and the oxygen consumption decreased. As would be expected, the possibilities for a discrepancy between the curves increase as the period is shortened and consequently we find on the night of May 4–5, when the experiment was divided into nine periods, that while the values as a whole are approximately parallel, in the sixth and seventh periods there is a great increase in the oxygen consumed which is unaccompanied by a corresponding increase in the carbon-dioxide production. Similar irregularities are to be noted on the night of May 13–14. In general, however, there is a striking tendency toward parallelism in the two curves.

After the first three nights of fasting, the minimum values for carbon dioxide and oxygen are usually found in the middle period of the night, *i. e.*, from 2 to 4 a. m., or thereabouts, the morning period almost inva-

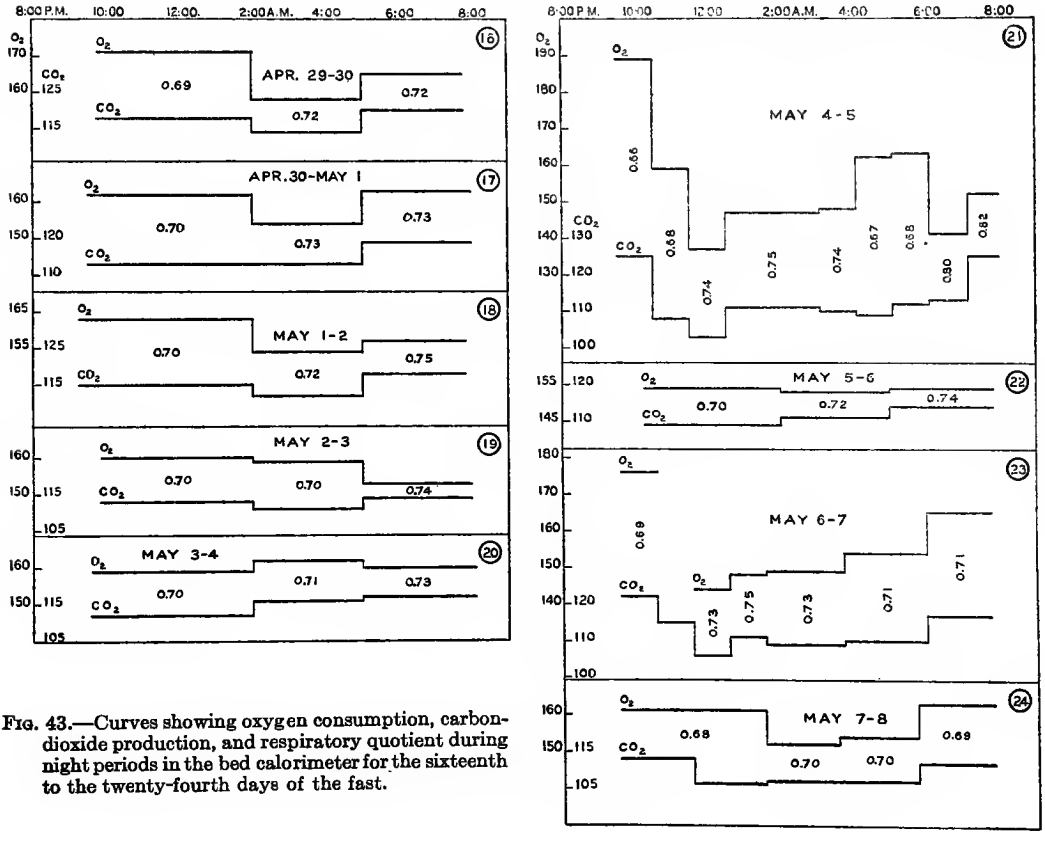


FIG. 43.—Curves showing oxygen consumption, carbon-dioxide production, and respiratory quotient during night periods in the bed calorimeter for the sixteenth to the twenty-fourth days of the fast.

riably showing a tendency to rise. This may be seen with great regularity throughout most of the curves, although there are enough exceptions (for instance, on May 4–5 and May 6–7) to make it inapplicable in all cases.

After the first few days of the fast, one would not expect a great change in the respiratory quotient, since there would be no material alteration in the character of the material oxidized in the body. An examination of the respiratory quotients given with the curves shows that they run not far from a constant value throughout the night with the different conditions of food and fasting. Thus, on the first few nights with food, the values are considerably above 0.80, but with the beginning of the fast they drop rapidly to about 0.74, remaining not far from 0.72 throughout the remainder of the fast. Occasionally certain fluctuations above or below the average figure may be observed,

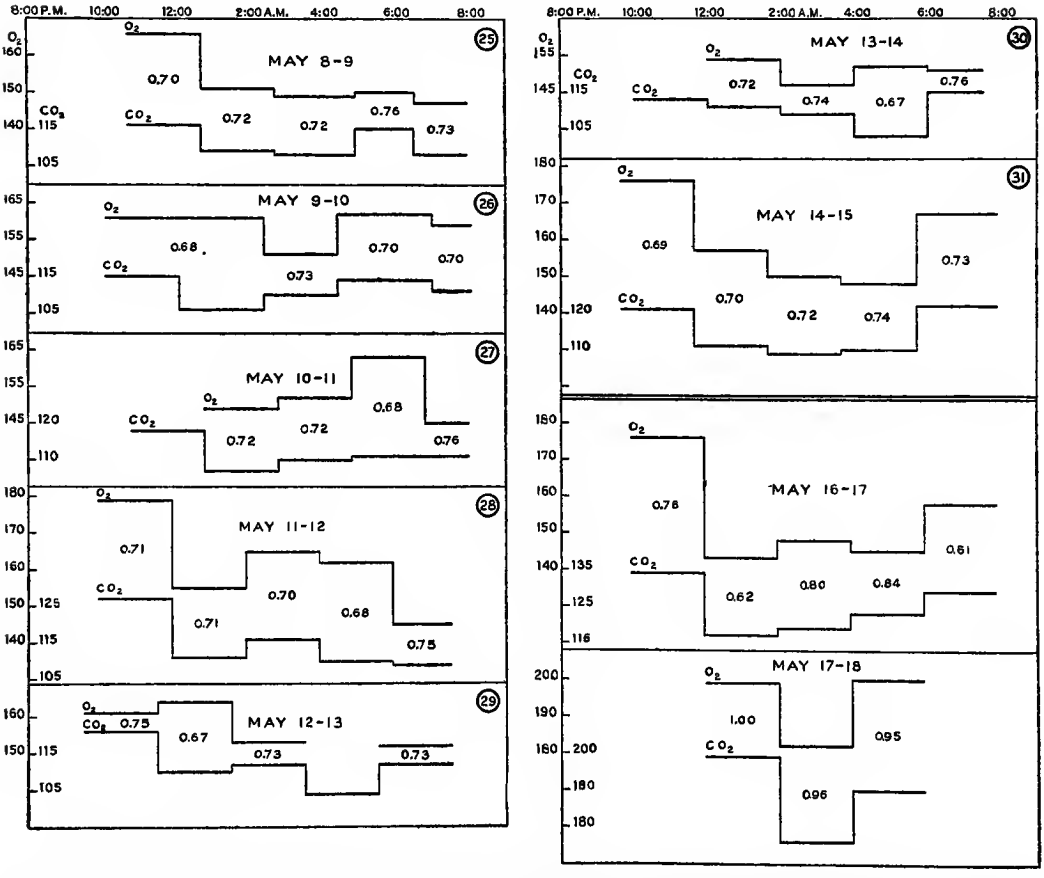


FIG. 44.—Curves showing oxygen consumption, carbon-dioxide production, and respiratory quotient during night periods in the bed calorimeter for the twenty-fifth to the thirty-first days of the fast and the second and third food days.

but these may easily be attributed to the fact that the shortness of the period affected the determinations of the oxygen consumption. It may be considered an established fact that respiratory quotients more than 0.02 above or below the average value for the night are due to accidental variations in the determinations. A low respiratory quotient following a high quotient may frequently be noted, showing that there is a compensation in the measurement of the oxygen consumption as the experiment continues.

Inasmuch as the determination of the respiratory quotient requires extremely accurate determinations of both the oxygen consumption and the carbon-dioxide production, it is obviously very much more difficult to secure accurate respiratory quotients than accurate measurements of either the carbon dioxide or the oxygen. Accordingly, while we feel that it is legitimate to accept the values for the carbon dioxide and even for the oxygen for short periods, we are by no means certain that we are justified in laying considerable stress upon the respiratory quotients in periods so short as those in the calorimeter experiments.

A careful scrutiny of all of the kymograph records shows that the extraneous muscular movements, although not absolutely constant in every period, are so slight that they may be practically neglected. Such movement as there was did not correspond closely to the general trend of the katabolism, for although the subject was more active during the morning period, the activity was not sufficient to account for the great difference in the katabolism. On the other hand, it is perfectly clear from his own records that the subject was usually in deep sleep in the middle of the night, as he often reported in the morning that he awoke about 4 a. m. and lay awake until the end of the experiment. A relationship between deep sleep and the metabolism is therefore indicated, a relationship which will be discussed in a subsequent section.

Perhaps the most striking fact shown by the whole series of curves is that the subject had by no means a constant metabolism. This man was living on a low metabolic plane, had a remarkable degree of muscular repose as shown by the kymograph records, and was without food in the alimentary tract; and yet, as has already been pointed out, the curves show a distinct tendency to fall off in the first part of the night until a minimum is reached from 2 to 4 a. m., and then to rise again in the later morning hours.

Total Metabolism.

The difficulties incidental to comparing the short-period values for the gaseous exchange are eliminated when one uses as a unit the results obtained during the entire sojourn of the subject inside the respiration chamber during any given night—that is, for a period of

10 or 12 hours. Consequently a comparison may be made of the results obtained for the individual nights as the fast progressed. We may, indeed, go further and compare not only the average values found throughout the night, but likewise the average values for the minimum periods in the experiments. While obviously there is an opportunity for possible error in thus selecting minimum periods, particularly in the measurements of the oxygen consumption, nevertheless it is believed that such errors will be equalized throughout a 31-day fast. Accordingly, in table 45 we give both the average and the minimum

TABLE 45.—*Gaseous exchange of subject L. during experiments in the bed calorimeter at night.*

Date.	Day of fast.	Carbon dioxide per minute.[1]		Oxygen per minute.[1]		Respiratory quotient. (A÷C)	Average pulse-rate.	Average body-temperature.
		Average. A	Minimum.[2] B	Average. C	Minimum.[2] D	E	F	G
1912.		*c.c.*	*c.c.*	*c.c.*	*c.c.*			° *C.*
Apr. 10–11	.....	224	218	276	265	0.81	82	.....
11–12	.....	228	217	258	246	.88	76	.....
12–13	.....	218	196	252	235	.86	78	.....
13–14	.....	180	173	221	208	.81	70	.....
14–15	1st....	165	152	212	196	.78	68	.....
15–16	2d.....	159	154	211	208	.75	66	36.41
16–17	3d.....	151	148	206	198	.73	62	.....
17–18	4th....	150	140	202	187	.74	65	36.55
18–19	5th....	143	137	192	176	.75	63	36.58
19–20	6th....	134	131	194	185	.68	60	36.44
20–21	7th....	135	132	190	185	.71	59	36.42
21–22	8th....	137	135	187	177	.73	61	36.55
22–23	9th....	134	131	178	173	.75	59	36.50
23–24	10th....	130	127	180	179	.72	57	36.64
24–25	11th....	128	124	176	166	.72	57	36.80
25–26	12th....	129	126	175	173	.73	58	36.85
26–27	13th....	126	125	171	167	.74	56	36.62
27–28	14th....	120	116	167	160	.72	53	36.30
28–29	15th....	117	114	163	162	.71	53	36.43
29–30	16th....	117	114	165	158	.71	53	36.40
Apr. 30–May 1	17th....	115	113	160	154	.72	52	36.42
May 1– 2	18th....	115	112	159	154	.72	52	36.30
2– 3	19th....	113	111	158	153	.71	52	36.21
3– 4	20th....	114	112	160	159	.71	52	36.51
4– 5	21st....	112	103	154	137	.73	54	36.12
5– 6	22d.....	111	109	154	153	.72	53	36.10
6– 7	23d.....	112	106	156	144	.72	56	35.98
7– 8	24th....	109	106	158	152	.69	55	35.88
8– 9	25th....	111	108	153	147	.72	55	36.31
9–10	26th....	111	106	159	151	.70	56	.....
10–11	27th....	111	107	153	145	.72	57	36.03
11–12	28th....	115	109	162	145	.71	59	36.37
12–13	29th....	112	104	158	152	.72	58	36.23
13–14	30th....	110	103	151	147	.72	58	36.06
14–15	31st....	115	109	160	148	.72	57	36.14
16–17	.....	124	117	154	143	.80	64	36.79
17–18	.....	188	176	194	182	.97	90	37.53

[1]For the duration of the period during which the metabolism was measured see table 44.

[2]The duration of the periods in which these minimum values were observed varies in general from 3 hours to 1 hour.

periodic values for the total gaseous exchange and the respiratory quotient for each night of the experiment.

The average for the carbon-dioxide production varied from 228 c.c. per minute on April 11–12 (the second night of the preliminary food period) to 109 c.c. on May 7–8 (the twenty-fourth night of the fast). The carbon-dioxide excretion during the fasting period was much less than during the days when food was taken, ranging from 165 c.c. on the first night to 109 c.c. on the twenty-fourth night. This increase with the taking of food is also shown in the two nights following the fasting period, when the carbon-dioxide production increased from 115 c.c. to 124 c.c. on the second night after the food was taken, and to 188 c.c. on the third night.

The minimum periods have a special interest, as they indicate the lowest plane of metabolism during the experiment. These values range from 218 c.c. on the first night with food to 103 c.c. on both the twenty-first and thirtieth nights of the fast. As with the average values, an increase after taking food is noted in the minimum periods for the two nights following the fast.

While the carbon dioxide of itself is a well-known index of the metabolism, particularly in fasting, when the character of the material burned remains relatively constant, nevertheless the values for oxygen likewise have significance. The average values for the oxygen consumption range from 276 c.c. on the first night with food to 151 c.c. on the thirtieth night of the fast. Considering only the fasting values, the oxygen consumed ranges from 212 c.c. on the first night of the fast to the minimum noted above. While no increase in the oxygen consumption is apparent in the first value obtained after the taking of food, a considerable increase is shown on May 17–18, the oxygen consumed being 194 c.c.

The minimum periodic values for the oxygen consumption can not be considered to have the same degree of accuracy as the minimum periodic values for the carbon-dioxide production, but a comparison is of interest. These values range from 265 c.c. on the first night with food to 137 c.c. on the twenty-first night of the fast. During the fasting period the range is from 208 c.c. on the second night of the fast to 137 c.c. on the twenty-first night. As with the average values, the minimum periodic values for the oxygen consumption do not show an increase after taking food until the third night.

From an examination of all of the data given in table 45 for the carbon-dioxide production and the oxygen consumption, it will be seen that there was a striking tendency for the total metabolism to decrease as the fast progressed. Both the average and the minimum periodic values show that the metabolism reached a low point about the twentieth day of the fast, and from that time to the end of the fast there was but little alteration.

The oxygen consumption showed the same general course as the carbon-dioxide production, there being a steady decrease until about the twentieth day. While the values for the oxygen between the twenty-first and the thirty-first days do not show the regularity that was observed with the carbon dioxide during the same period, they still do not fluctuate widely from the low value, the average values remaining between 151 c.c. and 162 c.c. and the values for the minimum periods between 137 c.c. and 153 c.c. It will be seen, therefore, that the metabolism as indicated by the carbon-dioxide production and the oxygen consumption decreased regularly until the twentieth day and from that time until the end of the fast remained essentially constant.

This observation is strikingly significant, inasmuch as one would naturally expect that, as the organism wasted away as a result of fasting, the total metabolism would decrease and likewise the intensity of the metabolism. The fact that the decrease in the metabolism did not continue beyond the twentieth day is the more surprising, since the loss in weight continued regularly throughout the fast. The absence of a continued decrease in the metabolism will subsequently be given special discussion.

Respiratory Quotient.

At present the best index we have of the *character* of the material burned in the body is the relationship between the volume of the carbon dioxide excreted and the oxygen consumed, *i. e.*, the so-called respiratory quotient. When carbohydrates are burned, the volume of carbon dioxide produced is equal to that of the oxygen consumed, the respiratory quotient being 1.0. On the contrary, when fat is burned, there is a much less volume of carbon dioxide produced per liter of oxygen and the respiratory quotient is not far from 0.7.

In the study of short fasts previously made at Wesleyan University, it was shown that the carbohydrates stored in the body (chiefly in the form of glycogen) were heavily drawn upon in the first few days of the fast and thereafter the body subsisted substantially upon fat and protein, but chiefly fat. In this fasting experiment, therefore, a rapid fall in the respiratory quotient would be expected during the first days of the fast, and a possible constancy during the remaining days, showing a combustion of fat.

By reference to the values for the respiratory quotient given in table 45, it will be seen that on the 4 nights prior to the fast the values ranged from 0.81 to 0.88, averaging not far from 0.84. This quotient is approximately that which would be expected with individuals subsisting upon a mixed diet. On the first day of fasting, the respiratory quotient fell to 0.78 and remained for the next few days not far from 0.74 to 0.75. On the sixth day a low value was found of 0.68, but for the remainder of the fast the respiratory quotient ranged above or

below the average of 0.72. No average value lower than 0.68 was found in any of the experiments. These respiratory quotients would indicate that the combustion in the body after the first few days of fasting was principally of fat. As will be seen later, there was the formation of a small amount of β-oxybutyric acid, which would have a tendency to lower slightly the respiratory quotient, but this would be in part compensated by the consumption of protein and a possible steady, though very small, oxidation of carbohydrate, both of which would tend to increase the respiratory quotient. Such an increase is indicated by the slightly higher average value of 0.72.

The two nights after the fast, when food had been taken, show a marked increase in the respiratory quotient, the quotient for May 16–17 being 0.80. On the night of May 17–18, when the whole alimentary tract of the subject was filled with carbohydrate material, due to the excessive amount of fruit juices and honey which he had taken, the extraordinarily high value of 0.97 was obtained.

The main conclusions to be drawn from the average respiratory quotients found in the experiments with the bed calorimeter as the fast progressed may be summed up as follows:

First, no very low values were found, such as have been observed and reported by other investigators. Quotients below 0.68 were very rarely found for the individual periods, and the average value for the 31 nights of the fast was 0.72.

Second, from the course of the respiratory quotients, it is clear that carbohydrate was burned on the first few days of fasting, which is in full conformity with the results found in the experiments carried out at Wesleyan University.

Finally, after the subject had fasted for 6 or 7 days, the respiratory quotients reached a point which indicated essentially a fat katabolism and continued at this point until the end of the fast, the formation of a small amount of β-oxybutyric acid tending to lower the respiratory quotient and the combustion of a small amount of protein, with possibly a small amount of glycogen, tending to increase the quotient above that which would be obtained with the combustion of pure fat.

Relationships of Pulse-Rate, Body-Temperature, and Metabolism.

In considering both the curves of the respiratory exchange and the average values shown in table 45, it should be noted that two of the factors affecting the total metabolism were absent, *i. e.*, muscular exercise and the digestion of food. Considering that the subject is living on a low metabolic plane, we might expect that the metabolism would be represented by a straight line, were it not for the influence of a third important factor—the internal muscular activity. The best index of the internal activity is the pulse-rate. Johansson[1] has also

[1]Johansson, Skand. Archiv f. Physiol., 1898, 8, p. 85.

pointed out that there is an intimate relationship between the body-temperature and the metabolism. It is important, therefore, to consider the relationship between the metabolism as shown by the gaseous exchange and these two indices of the internal condition.

It has seemed impracticable to complicate the curves in figures 41 to 44 by superimposing others, but a comparison can be made by referring to the curves for the pulse-rate and the body-temperature[1] given in previous sections of this publication. Such a comparison shows that the curves for the carbon-dioxide excretion, the oxygen consumption, the pulse-rate, and the body-temperature have in general the same course for each experiment, with a distinct tendency to fall off during the evening until a minimum is reached about the middle of the night, and then to rise in the morning. This parallelism with the metabolism is shown more clearly in the curves for the body-temperature, as there are more variations in the curves for the pulse-rate, but the general rhythm of the latter is much like that exhibited by the curves for the metabolism. Furthermore, there does not appear to be a material difference in these two relationships at the beginning and end of the fast, so that it would seem that fasting *per se* does not affect them. The body acts as a unit, therefore, irrespective of the state of nutrition. The intimate relationship between the pulse-rate and the metabolism (which has been emphasized in this laboratory for a number of years) and the relationship between the body-temperature and the metabolism are thus not only demonstrated in a remarkable manner, but are also shown to be unaffected by a prolonged fasting period.

The relationship between the pulse-rate and the total metabolism and the body-temperature and the metabolism as the fast progressed may be discussed more in detail in connection with the values given in table 45, using the average values rather than those for the minimum periods. In comparing these factors with the total metabolism on successive nights, it should be borne in mind that the relationships would not logically be expected to remain constant, for we have on the one hand the pulse-rate and the body-temperature governed by certain laws and on the other an organism producing heat, the heat-producing mechanism of which is constantly diminishing in size.

The pulse-records for the nights preceding the fast are somewhat irregular, but the technique for making the observations was not then so perfectly developed as it was later in the experiment and the assistant had not the time to make such frequent records. It will be seen, however, that the high pulse-rates were obtained with the high values for the carbon dioxide and the oxygen during the 4 nights prior to the fast and throughout the first 2 weeks of the fasting period. In the latter portion of the fast there was a distinct tendency for the average pulse-rate to increase without a corresponding increase in the total

[1]See figures 4 to 8, pages 90 to 94, and figures 12 to 18, pages 104 to 110.

carbon-dioxide output and oxygen intake. On May 17–18, however, the greatly increased pulse-rate was accompanied by a corresponding increase in both the carbon-dioxide output and the oxygen intake. In general, then, one may infer that even with an organism whose heat-producing mechanism is constantly decreasing in size, there is still an intimate relationship between the pulse-rate per minute and the total heat production. It should also be recognized that this relationship was somewhat disturbed during the latter portion of the fast, but not sufficiently disturbed as not to be again apparent on the third day with food.

The body-temperature was not recorded on the nights preceding the fast, but observations were made nearly every night of the fast and for two nights following. The values given in table 45 for the fasting period have a distinct tendency to remain not far from an average value of 36.36° C., and range from 36.85° C. on the twelfth night of the fast to 35.88° C. on the twenty-fourth night. From the twenty-first night of the fast, the values for the most part lie distinctly below the average of the first 3 weeks of the fasting period; but little if any relationship is shown between the average body-temperature and the total metabolism. On the other hand, on the last night of observation after the fast (May 17–18), the increased metabolism and increased pulse-rate were accompanied by the highest average temperature found on any night with this subject.

It is evident, therefore, that while there is a tendency towards a parallelism of the body-temperature and the metabolism throughout any given night, there is no distinct tendency towards parallelism between the average temperatures of successive nights and the total metabolism as measured. Evidently the heat-regulating mechanism of the body is in large part independent of the total heat-production or of the condition of nutrition of the subject.

STUDIES WITH THE UNIVERSAL RESPIRATION APPARATUS.

The facility with which experiments could be carried out with the universal respiration apparatus made it specially adapted for measuring the metabolism of the fasting subject under various conditions, such as lying awake, sitting up either quietly or writing, or lying awake breathing an oxygen-rich atmosphere. It was also possible to obtain accurate determinations of the respiratory quotient with this apparatus. This was of special importance, since it was desired to establish as sharply as possible the respiratory quotient obtaining during prolonged fasting, particularly as the low quotients found by Luciani and by Zuntz and his co-workers have been the subject of much discussion. Consequently it was decided that, throughout the entire fast, respiration experiments would be made as frequently as practicable in which the respiratory exchange would be determined under various condi-

tions. A summary of the data obtained in these experiments is given in table 46.

For purposes of comparison the oxygen absorbed and the carbon dioxide produced were calculated on the basis of cubic centimeters per minute. The respiratory quotient for each experiment and the average pulse-rate are also given in this table. The morning respiration experiments were made immediately following the calorimeter

TABLE 46.—*Gaseous exchange of subject L. at different times of the day and with varying activity. (Respiration apparatus.)*

Date.	Day of fast.	Lying (usually 8h 30m a.m. to 9h 30m a.m.).				Lying (usually 7 p.m. to 7h 45m p.m.).			
		Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Average pulse-rate.	Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Average pulse-rate.
1912.		c.c.	c.c.			c.c.	c.c.		
Apr. 11	.....	186	231	0.81	72	...	...	...	..
12	.....	196	220	.89	73	...	...	...	..
13	.....	200	225	.89	72	...	...	...	..
14	.....	182	223	.82	73	...	...	...	..
15	1st....	185	237	.78	74	...	...	...	..
16	2d.....	180	227	.79	73	...	...	...	..
17	3d.....	169	226	.75	70	...	...	...	..
18	4th....	159	212	.75	68	...	...	...	..
19	5th....	158	205	.77	67	...	...	...	..
20	6th....	148	200	.74	64	...	...	...	..
21	7th....	153	204	.75	64	...	...	...	..
22	8th....	151	203	.74	65	...	...	...	..
23	9th....	143	190	.75	63	...	...	...	..
24	10th....	143	187	.76	63	...	...	...	..
25	11th....	140	187	.75	61	...	...	...	..
26	12th....	140	187	.75	61	139	193	0.72	62
27	13th....	140	192	.73	59	[1]136	[1]195	[1].70	[1]59
28	14th....	134	181	.74	58	134	190	.71	59
29	15th....	132	179	.74	57	137	189	.72	61
30	16th....	133	182	.73	58	134	190	.71	59
May 1	17th....	130	182	.71	57	130	188	.69	61
2	18th....	123	174	.71	56	128	189	.68	62
3	19th....	127	177	.72	57	126	182	.69	60
4	20th....	124	173	.72	58	...	...	...	..
5	21st....	126	174	.73	59	125	182	.69	57
6	22d.....	124	170	.73	59	125	176	.71	63
7	23d.....	121	165	.73	58	126	175	.72	60
8	24th....	122	167	.73	59	125	177	.71	63
9	25th....	125	166	.75	60	124	176	.70	63
10	26th....	123	168	.73	61	128	180	.71	66
11	27th....	129	172	.75	62	126	181	.70	66
12	28th....	124	166	.75	61	123	178	.69	66
13	29th....	124	171	.73	63	123	178	.69	67
14	30th....	119	166	.72	59	127	183	.69	71
15	31st....	120	166	.72	60	...	...	...	..
17	.....	133	170	.78	72	...	...	...	..
18	.....	172	183	.94	84	...	...	...	..

[1]During a period from 3h 16m p.m. to 3h 51m p. m. on this day, with the subject in the lying position, the observations were: Carbon dioxide, 140 c.c.; oxygen, 189 c.c.; respiratory quotient, 0.74; pulse-rate, 61 per minute.

TABLE 46.—*Gaseous exchange of subject L. at different times of the day and with varying activity. (Respiration apparatus.)*—Continued.

Date.	Day of fast.	Sitting.[1] Period.	Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Average pulse-rate.
1912.			c.c.	c.c.		
Apr. 16....	2d.....	4h 00m p.m. to 4h 35m p.m.	179	244	0.73	82
19....	5th....	4 10 p.m. 4 43 p.m.*	198	269	.74	80
23....	9th....	3 52 p.m. 4 28 p.m.	129	187	.69	62
24....	10th....	3 58 p.m. 4 57 p.m.	144	194	.74	69
26....	12th....	3 13 p. m. 4 11 p.m.	124	183	.68	60
27....	13th....	12 14 p.m. 12 48 p.m.	141	200	.71	68
29....	15th....	3 23 p.m. 3 56 p.m.*	164	233	.70	68
May 1....	17th....	9 31 a.m. 10 04 a.m.*	153	215	.71	69
4....	20th....	9 35 a.m. 10 10 a.m.*	141	208	.68	65
7....	23d.....	3 43 p.m. 4 14 p.m.*	159	222	.72	69
14....	30th....	6 32 p.m. 7 02 p.m.*	156	221	.71	75

[1]Periods indicated by an asterisk were obtained with the subject sitting, writing.

experiment, with the subject still lying upon the couch in essentially the same position as when he left the calorimeter chamber. The evening respiration experiments were made in the latter days of the fast just before the subject entered the calorimeter chamber. The experiments when the subject was sitting were of two kinds. In certain experiments he sat quietly in his chair, but in others he was writing, exactly as is shown in plate 1, figure B. It is thus seen that observations were made with this fasting subject on every day of the fast and on certain days experiments were made in several body positions. These data also give an indication of the diurnal variations in the katabolism, since observations were made under identical body conditions, so far as muscular activity and absence of food are concerned, both in the morning after the subject left the calorimeter and in the evening on the same day just prior to entering the chamber for the night.

VARIATIONS IN THE METABOLISM AS THE FAST PROGRESSED.

The carbon-dioxide production of the subject while lying on the couch in the morning respiration experiments ranged from 200 c.c. on the morning of April 13 (one of the days preceding the fast) to 119 c.c on May 14 (the thirtieth day of fasting). During the fasting period the values ranged from 185 c.c. to 119 c.c. When the subject again took food the rise in the carbon-dioxide production was very noticeable, particularly on the last day of observation.

In general, the data obtained for the oxygen consumption nearly paralleled those for the carbon-dioxide production. The maximum

value of 237 c.c. was obtained on the first day of the fast, while the minimum value of 165 c.c. was found on the twenty-third day of the fast. The striking constancy shown in the values for the oxygen consumption on the first four mornings prior to the fast and on the first day of the fasting period is worthy of special notice, as it gives evidence in the first place of the remarkable constancy in the katabolism of this man and likewise of the regularity of his muscular repose. Both the carbon-dioxide production and the oxygen consumption fell off as the fast progressed, and although the minimum value for the oxygen consumption was reached on the twenty-third day, yet the remaining days of the fasting period indicate a katabolism not far from the minimum value of 165 c.c. It is of particular interest to note that on the 17th of May, *i. e.*, the second day of taking food, the metabolism had not materially increased, as shown by the oxygen consumption, but on the last morning (May 18) there was a marked increase from 170 c.c. to 183 c.c.

The trend of the respiratory quotient is likewise significant. On the first 4 days with food, the respiratory quotient varied from 0.81 to 0.89, this being not far from the average respiratory quotient found with normal individuals subsisting on a mixed diet. At the beginning of the fast, the respiratory quotient was a little lower on the first few days and then steadily decreased until a minimum value of 0.71 was found on the seventeenth and eighteenth days. During the remainder of the fast, the value for the respiratory quotient remained at about 0.73. On the second day with food it rose to 0.78, and on the third day with food it reached the extraordinarily high value of 0.94, indicating that the subject was surcharged with carbohydrate material. The absence of very low quotients during the fast was noticeable. It should be borne in mind that the values for the oxygen consumption represent more nearly the true index of the total metabolism than do the values for the carbon-dioxide production, particularly in the 4 days with food preceding the fast and the first few days of fasting. After the third or fourth day of fasting, however, the values for the carbon-dioxide production and the oxygen consumption were essentially parallel, so that either may be looked upon as a true measure of the total metabolism.

RELATIONSHIP BETWEEN THE PULSE-RATE AND THE METABOLISM.

The pulse-rate remained remarkably constant for the first 4 days with food before the fast and likewise on the first few days of fasting, ranging from 72 to 74, which is in general conformity with the measurements of the oxygen consumption. It then fell with a considerable degree of regularity until a minimum value of 56 was reached on the eighteenth day of the fast. Subsequently the values show a slight, though definite, tendency to rise gradually to the end of the fasting period. The increase on the second day after food was taken was

considerable, with a still further increase on the last day on which the observations were made.

A careful examination of the fluctuations in the values for the oxygen consumption and the pulse-rate shows a remarkable regularity in the relationship between them, although the absolute minimum values were not found on the days that the minimum pulse-rate was found. On the second day with food after the fast, the pulse-rate rose to 72 and the oxygen consumption likewise rose, reaching 170 c.c. The values taken as a whole, however, show that in the earlier days of this long fast the relationship between the oxygen consumption and the pulse-rate was reasonably close, but in the latter part of the fasting period there was a slight divergence, as a somewhat increased pulse-rate was occasionally accompanied by an actual decrease in the oxygen consumption. It should be considered, however, that the organism was changing from day to day, and while the total tissue available for metabolism was slowly decreasing the pulse-rate may still have a definite relationship to the total active tissue remaining. Thus a decrease in the amount of tissue may in part be compensated for by an increase in the pulse-rate, although this latter factor may still have too small an effect to prevent a lowering of the total metabolism. Further discussion along this line must be deferred until the metabolism per unit of body-weight and per unit of body-surface are considered.

DIURNAL VARIATIONS IN METABOLISM.

The determination of the respiratory exchange at various times during the day gives an excellent opportunity for studying the diurnal variations in the metabolism of the same individual during fasting. The data given in table 46 show that the metabolism during the evening experiments was invariably higher than in the morning experiments, regardless of whether the carbon-dioxide production or the oxygen consumption is used as an index.

The pulse-rate was also a few beats higher in the evening hours, thus indicating a close relationship between the pulse-rate and the metabolism. The slight tendency for the pulse-rate to rise in the morning experiments beginning with the eighteenth day of the fast and continuing to the end was even more marked in the records of the pulse-rate for the series of evening experiments, in which the minimum value of 57 was found on the twenty-first day of the fast and the maximum of 71 on the thirtieth day. A general relationship between the oxygen consumption and the pulse-rate is shown throughout all of the series of experiments, although as the fast progressed this relationship was not so pronounced as at the beginning. It should be considered here again, however, that the active mass of protoplasmic tissue was gradually decreasing, so that the relationship can not be expected to hold constant.

The respiratory quotients obtained in the evening were not unlike those obtained in the morning experiments, with a slight tendency for the early evening quotients to be somewhat lower than those obtained in the morning experiments. This lowering of the quotient in the evening experiments might be taken as an indication that there may have been a formation of carbohydrate from fat by a storage of oxygen, or a greater formation of β-oxybutyric acid, and that the next morning either the formation of the β-oxybutyric acid was less or that the slight supply of glycogen formed during the early evening was being burned. Unfortunately, although these respiratory quotients were determined with the best technique that we know of at present, we do not feel justified in laying much stress upon a change of one or two units in the quotients.

EXTERNAL INFLUENCES UPON METABOLISM.

While the values for the carbon-dioxide output, the oxygen intake, the respiratory quotient, and the pulse-rate are given in table 46 for the experiments in which the subject was lying upon a couch and sitting up in a chair, either writing or quietly at rest, a better understanding of the influence of a change in conditions may perhaps be secured by studying each change by itself. To this end several small tables have been prepared which show the influence of the change in condition upon the total metabolism and also upon the mechanics of respiration.

Effect of Changes in Body Position.

On the second, tenth, twelfth, and thirteenth days of the fast, the metabolism was studied while the subject was sitting in a chair. It was thus possible to compare the metabolism and the mechanics of respiration for the two positions. This comparison is made in table 47, in which is given the increase or decrease in the values due to the change to the sitting position. The figures show that in general there was practically no increase in the carbon-dioxide production—and, indeed, in two instances a considerable decrease. The oxygen consumption was increased in 3 out of the 5 experiments, with a slight decrease in the other 2, and there was a perceptible though probably not significant change in the respiratory quotient, which may have been caused by the absence of change in the carbon-dioxide production. There was an average increase in the pulse-rate and respiration-rate and an increase in the lung ventilation, but varying results in the volume per respiration.

Since the lying experiments were made in the early morning and the sitting experiments late in the afternoon, they are not, strictly speaking, comparable. On the other hand, one would expect that there would be a higher metabolism normally in the late afternoon than in the morning after the subject came out of the calorimeter, and it is accordingly very

difficult to explain the results obtained on the ninth and twelfth days of the fast, when there was an actual decrease in the oxygen consumption, with a slight falling off of the pulse-rate.

The general course of the metabolism noted on the second, tenth, and thirteenth days is essentially that which is found with normal individuals—namely, a small increase due to the position of sitting. This increase was also accompanied by an increased pulse-rate. The parallelism shown here between the increase of the oxygen consumption and the pulse-rate is worthy of special attention.

The figures also show that the change to the position of sitting invariably results in an increased ventilation of the lungs, although the respiration-rate changes so that the actual volume per inspiration may be above or below that when the subject was lying. No positive deductions can be drawn as to the influence of the change in position upon the volume per inspiration. If an average of these five experiments were permissible, it would be seen that there was an increase in metabolism of not far from 5 c.c. per minute, or about 2 to 2.5 per cent

TABLE 47.—*Comparison of the gaseous exchange and lung ventilation of subject L., lying on couch and sitting in chair. (Respiration apparatus.)*

Date.	Day of fast.	Position.	No. of periods.	Time.	Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Respiration rate.	Lung ventilation per minute.[1]	Volume per inspiration.[2]	Pulse-rate.
1912.					c.c.	c.c.			*liters.*	c.c.	
Apr. 16	2d	Lying.....	3	8h 34m a.m. to 9h 37m a.m.	180	227	0.79	10.9	5.18	576	73
		Sitting....	2	4h 00m p.m. to 4h 35m p.m.	179	244	.73	10.3	5.58	660	82
		Increase..	....	.....	−1	17	....	−.6	.40	84	9
Apr. 23	9th	Lying.....	3	8h 25m a.m. to 9h 18m a.m.	143	190	0.75	12.1	4.65	476	63
		Sitting....	2	3h 52m p.m. to 4h 28m p.m.	129	187	.69	16.7	5.48	402	62
		Increase..	....	.....	−14	−3	....	4.6	.83	−74	−1
Apr. 24	10th	Lying.....	3	8h 19m a.m. to 9h 37m a.m.	143	187	0.76	10.9	4.55	504	63
		Sitting....	3	3h 58m p.m. to 4h 57m p.m.	144	194	.74	14.6	5.83	484	69
		Increase..	....	.....	1	7	....	3.7	1.28	−20	6
Apr. 26	12th	Lying.....	3	8h 21m a.m. to 9h 26m a.m.	140	187	0.75	12.8	4.64	429	61
		Sitting....	3	3h 13m p.m. to 4h 11m p.m.	124	183	.68	15.8	5.37	404	60
		Increase..	....	.....	−16	−4	....	3.0	.73	−25	−1
Apr. 27	13th	Lying.....	3	8h 37m a.m. to 9h 33m a.m.	140	192	0.73	12.8	4.63	437	59
		Sitting....	2	12h 14m p.m. to 12h 48m p.m.	141	200	.71	12.8	5.55	525	68
		Increase..	....	.....	1	8	....	0.0	.92	88	9

[1]The lung ventilation observed is here reduced to 0° C. and 760 mm. pressure.
[2]Calculated to the pressure existing in the lungs and to 37° C.

of the oxygen consumption. In the light of these varying results, it is to be regretted that further observations were not made with the subject sitting quietly. However, a number of observations made when the man was sitting up and writing actively may also be compared.

Influence of the Work of Writing.

On the fifth, fifteenth, seventeenth, twentieth, twenty-third, and thirtieth days of the fast, the metabolism was studied while the subject was sitting up writing, an employment that occupied much of his spare time during the entire fast. These six experiments are compared in table 48 with data obtained on the same day when the subject was lying upon the couch in the morning experiment. Two of these experiments—those on the seventeenth and twentieth days—immediately

Table 48.—*Comparison of the gaseous exchange and lung ventilation of subject L., lying on couch and sitting writing.* (*Respiration apparatus.*)

Date.	Day of fast.	Position.	No. of periods.	Time.	Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Respiration-rate.	Lung ventilation per minute.[1]	Volume per inspiration.[2]	Pulse-rate.
1912.					c.c.	c.c.			*liters.*	c.c.	
Apr. 19	5th	Lying.....	4	8h 21m a.m. to 9h 32m a.m.	158	205	0.77	11.8	4.88	507	67
		Writing...	2	4h 10m p.m. to 4h 43m p.m.	198	269	.74	17.9	7.54	517	80
		Increase.....		.....	40	64	....	6.1	2.66	10	13
Apr. 29	15th	Lying.....	3	8h 19m a.m. to 9h 19m a.m.	132	179	0.74	12.3	4.55	446	57
		Writing...	2	3h 23m p.m. to 3h 56m p.m.	164	233	.70	18.7	7.88	510	68
		Increase.....		.....	32	54	....	6.4	3.33	64	11
May 1	17th	Lying.....	3	8h 22m a.m. to 9h 19m a.m.	130	182	0.71	12.3	4.81	471	57
		Writing...	2	9h 31m a.m. to 10h 04m a.m.	153	215	.71	14.6	6.57	542	69
		Increase.....		.....	23	33	....	2.3	1.76	71	12
May 4	20th	Lying.....	3	8h 22m a.m. to 9h 15m a.m.	124	173	0.72	14.3	4.90	413	58
		Writing...	2	9h 35m a.m. to 10h 10m a.m.	141	208	.68	15.3	6.22	490	65
		Increase.....		.....	17	35	....	1.0	1.32	77	7
May 7	23d	Lying.....	3	8h 15m a.m. to 9h 17m a.m.	121	165	0.73	14.0	4.76	410	58
		Writing...	2	3h 43m p.m. to 4h 14m p.m.	159	222	.72	16.1	7.62	573	69
		Increase.....		.....	38	57	....	2.1	2.86	163	11
May 14	30th	Lying.....	3	8h 03m a.m. to 8h 56m a.m.	119	166	0.72	14.8	4.80	391	59
		Writing...	2	6h 32m p.m. to 7h 02m p.m.	156	221	.71	17.8	8.05	546	75
		Increase.....		.....	37	55	....	3.0	3.25	155	16

[1]The lung ventilation observed is here reduced to 0° C. and 760 mm. pressure.
[2]Calculated to the pressure existing in the lungs and to 37° C.

followed the morning experiments, and it is again to be regretted that this routine was not carried out in all cases.

There was a noticeable increase in the metabolism in all of the writing experiments, which is shown by both the carbon-dioxide excretion and the oxygen consumption, but the respiratory quotient tended to become a few points lower during the writing period. The pulse- and respiration-rates were both invariably increased, the increase in the pulse-rate ranging from 7 to 16 beats per minute. The ventilation of the lungs per minute likewise increased very considerably during the writing experiment, this increase at times amounting to $3\frac{1}{3}$ liters. The volume per inspiration did not increase materially, except on the twenty-third and thirtieth days of the fast.

Under ordinary conditions one would normally expect an increased metabolism in the afternoon over the morning, but the comparison previously made between the metabolism for the lying and sitting positions showed no increase for the sitting position in some instances and in others there was an actual decrease. Consequently a sharp comparison is difficult to make for the writing experiments.

We may assume from these experiments, however, that when the subject was writing there was invariably an increased metabolism, but that on the 2 days when the writing experiment immediately followed the lying experiment the increase was only 50 to 75 per cent of that obtained on the days when the writing experiment was in the afternoon. On the seventeenth and twentieth days of fasting, when the writing experiments were in the morning, the increase in the metabolism due to writing was represented by an increased consumption of about 35 c.c. of oxygen, or not far from 20 per cent. The absolute maximum increase of 64 c.c. above the lying position on the fifth day of the fast amounted to approximately 30 per cent, but while the absolute increase on the twenty-third and thirtieth days was a few cubic centimeters less, the percentage increase was greatest, *i. e.*, 34 and 33 per cent respectively.

The work of writing, therefore, produced a distinct increase in the metabolism, which is shown not only by the increase in the carbon-dioxide production and the oxygen consumption, but also by an increase in the respiration-rate, the ventilation of the lungs, and the volume per inspiration. Finally, there was a regular and distinct increase in the pulse-rate. These values are used subsequently in computing the probable metabolism of this subject during several hours in the day when he sat in the balcony and wrote.

Influence of Breathing an Oxygen-rich Atmosphere.

On the twenty-eighth, twenty-ninth, and thirtieth days of the fast a series of experiments was made in which the subject breathed an oxygen-rich atmosphere varying from 95 to 75 per cent of oxygen. At the beginning of each experiment the percentage of oxygen in the

atmosphere was probably not far from 95 per cent. This fell off quite rapidly through the experimental period, so that at the end of the experiment the proportion of oxygen in the atmosphere was between 75 and 80 per cent. The results of these experiments are not included in table 46, but are compared in table 49 with the morning experiments in which the subject breathed a normal atmosphere. In each case the oxygen experiment immediately followed the regular morning experiment.

TABLE 49.—*Comparison of the gaseous exchange and lung ventilation of subject L., breathing different air mixtures. (Respiration apparatus, subject lying, in the morning.)*

Date.	Day of fast.	Air mixture.	No. of periods.	Carbon dioxide per minute.	Oxygen per minute.	Respiratory quotient.	Alveolar carbon dioxide.	Respiration-rate.	Lung ventilation per minute.[1]	Volume per inspiration.[2]	Pulse-rate.
1912.				*c.c.*	*c.c.*		*p. ct.*		*liters.*	*c.c.*	
May 12	28th	Normal.....	3	124	166	0.75	3.66	14.8	5.04	410	61
		Oxygen-rich...	2	137	179	.77	3.43	13.6	5.50	487	62
		Increase....	..	13	13	....	−.23	−1.2	.46	77	1
May 13	29th	Normal.....	3	124	171	0.73	3.67	14.1	4.96	426	63
		Oxygen-rich...	2	130	176	.74	3.34	14.0	5.44	471	61
		Increase....	..	6	5	....	−.33	−.1	.48	45	−2
May 14	30th	Normal.....	3	119	166	0.72	3.80	14.8	4.80	391	59
		Oxygen-rich...	2	130	169	.77	3.44	14.2	5.34	454	58
		Increase....	..	11	3	....	−.36	−.6	.54	63	−1

[1]The lung ventilation observed is here reduced to 0° C. and 760 mm. pressure.
[2]Calculated to the pressure existing in the lungs and to 37° C.

This series of experiments may be compared with an extensive research made in this laboratory by Mr. H. L. Higgins on the influence upon the metabolism of normal individuals of breathing oxygen-rich atmospheres. In the previous experimenting it was found that there was no evidence of the increased percentage of oxygen affecting the respiratory exchange, but there was a slight tendency for the pulse-rate to decrease with an increase in the percentage of oxygen. In the experiments with L., observations were made of the effect on the carbon-dioxide excretion, oxygen consumption, respiratory quotient, the respiration-rate, lung ventilation, volume per inspiration, alveolar carbon dioxide, and the pulse-rate.

The data given in table 49 show a slight increase in the metabolism indicated by both the carbon-dioxide production and the oxygen consumption. The respiration-rate had a tendency to fall off somewhat;

the lung ventilation was considerably increased—the increase ranging from 0.46 liter to 0.54 liter—and the volume per inspiration was likewise increased from 45 c.c. to 77 c.c. per inspiration. The pulse-rate was but little affected.

It is clear, therefore, that, even with an emaciated subject after a prolonged fast, the inhalation of an oxygen-rich atmosphere did not materially affect the carbon-dioxide production and oxygen consumption, the slight increase being not far from 7 c.c. or approximately 5 per cent. The increase in the lung ventilation was, however, considerable, amounting to about 10 per cent. This has special significance with reference to the clinical use of oxygen, since it has been contended that one of the advantages in the clinical administration of oxygen was the fact that the patient was able to secure a sufficient amount of oxygen for the aeration of the blood with less effort than would be required to pump the lungs full of ordinary room air. The larger ventilation of the lungs in the oxygen experiments would imply that the increased amount of oxygen from inhaling an oxygen-rich atmosphere was obtained with a greater mechanical effort, which would thus offset the supposed advantage of this method of securing a suitable percentage of oxygen for the oxygenation of the blood.

Influence of Sleep.

The measurements of the metabolism in the bed-calorimeter experiments were made for the most part when the subject was resting very quietly. During a portion of the time he was asleep; it is equally certain that during certain periods he was awake. The results obtained, therefore, show the metabolism of a subject who was a part of the time awake and a part of the time asleep.

The kymograph curves also show that there was but little muscular activity, so this can be eliminated in studying the factors influencing the metabolism. As the subject was fasting, the influence of the ingestion of food may likewise be left out of consideration. Hence we have an ideal condition for studying the basal metabolism of the subject.

According to the prevailing belief, with a complete absence of muscular activity and of food in the alimentary tract, the metabolism should have a constant value. But, as was pointed out in discussing the metabolism curves, the course is irregular, the minimum values apparently being secured in the periods of the night when the subject was in the deepest sleep. Notwithstanding the fact that it is believed by many investigators that sleep *per se* has no influence upon the metabolism, such an influence is indicated in the curves shown.

In the morning experiments with the respiration apparatus, the measurements of the metabolism were made under exactly the same conditions as to the absence of muscular activity and the ingestion of food as were the calorimeter experiments, the only difference being

that the measurements were made with another apparatus and the subject was awake throughout the whole experiment. We have, therefore, as a result of the experiments with the respiration apparatus, the basal minimum metabolism of the subject when he was awake.

It is accordingly of great interest to compare the metabolism as measured in the bed calorimeter during the night with the metabolism as measured with the respiration apparatus in the morning immediately after the subject has been taken out of the calorimeter chamber. Such a comparison has been made in table 50, in which the average carbon-dioxide production and oxygen consumption are given for the bed-calorimeter experiments when the subject was a part of the time asleep and a part of the time awake, and also for the minimum periods when the subject was presumably in deep sleep. The average values for the carbon-dioxide production and the oxygen consumption are likewise given for the experiments with the respiration apparatus, in which the subject was awake throughout the whole period. The comparison of these values is also made by noting the increase when the subject was awake. In the same table the minimum level of the pulse-rate observed in the bed-calorimeter experiments[1] is compared with the average pulse-rate for the experiments with the respiration apparatus. The increase in the pulse-rate when the subject was awake in the experiments with the respiration apparatus is also shown. Finally, the respiratory quotients obtained in the bed-calorimeter experiments and in the experiments with the respiration apparatus are compared.

In comparing the results obtained during the first 4 days of the experiment, when the subject was taking food, we find that the carbon-dioxide production was 32 c.c. less per minute on the first day than during the minimum period in the bed calorimeter when the subject was asleep. On the night of April 12–13, the carbon-dioxide production was lower by 4 c.c. and on the following night by 9 c.c. per minute when the subject was asleep than when awake. These values, however, present no abnormalities, since they are easily explained by the previous ingestion of carbohydrate-rich food in the evening meal. This resulted in a greater production of carbon dioxide in the bed-calorimeter experiment than was obtained in the experiment with the respiration apparatus, when the subject was without breakfast and therefore in the post-absorptive condition. The values for the oxygen consumption followed approximately the same course. The pulse-rate, also, in two instances was less in the morning experiment than it was the night previous and in two others it was 3 and 9 beats higher.

However, the results obtained on days when food was taken are not of such great interest as those obtained during the fasting period. Beginning with the first night of the fast, it will be seen that in the

[1]See curves showing the pulse-rate in the bed-calorimeter experiments in figures 12 to 18, on pages 104 to 110.

TABLE 50.—*Comparison of the gaseous exchange of subject L., in the bed calorimeter at night and awake on the respiration apparatus in the morning.*

Date.	Day of fast.	Carbon dioxide per minute.				Oxygen per minute.				Pulse-rate.			Respiratory quotient.	
		Bed calorimeter.		Respiration apparatus.	Increase while awake (C—B).	Bed calorimeter.		Respiration apparatus.	Increase while awake (G—F).	Bed calorimeter (minimum).[2]	Respiration apparatus.	Increase while awake (J—I).	Bed calorimeter (A÷E).	Respiration apparatus. (C÷G)
		Average.	Minimum.[1]			Average.	Minimum.[1]							
		A	B	C	D	E	F	G	H	I	J	K	L	M
1912.		*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*					
Apr. 10–11[3]	.....	224	218	186	−32	276	265	231	−34	76	72	−4	0.81	0.81
11–12[3]	.....	228	217	196	−21	258	246	220	−26	70	73	3	.88	.89
12–13[3]	.....	218	196	200	4	252	235	225	−10	73	72	−1	.86	.89
13–14[3]	.....	180	173	182	9	221	208	223	15	64	73	9	.81	.82
14–15	1st	165	152	185	33	212	196	237	41	64	74	10	.78	.78
15–16	2d	159	154	180	26	211	208	227	19	63	73	10	.75	.79
16–17	3d	151	148	169	21	206	198	226	28	60	70	10	.73	.75
17–18	4th	150	140	159	19	202	187	212	25	58	68	10	.74	.75
18–19	5th	143	137	158	21	192	176	205	29	59	67	8	.75	.77
19–20	6th	134	131	148	17	194	185	200	15	57	64	7	.68	.74
20–21	7th	135	132	153	21	190	185	204	19	56	64	8	.71	.75
21–22	8th	137	135	151	16	187	177	203	26	58	65	7	.73	.74
22–23	9th	134	131	143	12	178	173	190	17	57	63	6	.75	.75
23–24	10th	130	127	143	16	180	179	187	8	55	63	8	.72	.76
24–25	11th	128	124	140	16	176	166	187	21	54	61	7	.72	.75
25–26	12th	129	126	140	14	175	173	187	14	56	61	5	.73	.75
26–27	13th	126	125	140	15	171	167	192	25	54	59	5	.74	.73
27–28	14th	120	116	134	18	167	160	181	21	51	58	7	.72	.74
28–29	15th	117	114	132	18	163	162	179	17	51	57	6	.71	.74
29–30	16th	117	114	133	19	165	158	182	24	52	58	6	.71	.73
Apr. 30–May 1	17th	115	113	130	17	160	154	182	28	49	57	8	.72	.71
May 1– 2	18th	115	112	123	11	159	154	174	20	51	56	5	.72	.71
2– 3	19th	113	111	127	16	158	153	177	24	50	57	7	.71	.72
3– 4	20th	114	112	124	12	160	159	173	14	51	58	7	.71	.72
4– 5	21st	112	103	126	23	154	137	174	37	51	59	8	.73	.73
5– 6	22d	111	109	124	15	154	153	170	17	51	59	8	.72	.73
6– 7	23d	112	106	121	15	156	144	165	21	53	58	5	.72	.73
7– 8	24th	109	106	122	16	158	152	167	15	53	59	6	.69	.73
8– 9	25th	111	108	125	17	153	147	166	19	53	60	7	.72	.75
9–10	26th	111	106	123	17	159	151	168	17	54	61	7	.70	.73
10–11	27th	111	107	129	22	153	145	172	27	55	62	7	.72	.75
11–12	28th	115	109	124	15	162	145	166	21	57	61	4	.71	.75
12–13	29th	112	104	124	20	158	152	171	19	55	63	8	.72	.73
13–14	30th	110	103	119	16	151	147	166	19	55	59	4	.72	.72
14–15	31st	115	109	120	11	160	148	166	18	54	60	6	.72	.72
16–17[3]	.....	124	117	133	16	154	143	170	27	60	72	12	.80	.78
17–18[3]	.....	188	176	172	−4	194	182	183	1	84	84	0	.97	.94

[1]The duration of the periods in which these minimum values were observed varies in general from 3 hours to 1 hour.

[2]Represents period of lowest pulse-rate observed. See page 112.

[3]On the days preceding and following the fast the night experiments were made after the ingestion of food. The subject was without breakfast during the morning respiration experiments.

morning experiment 33 c.c. more of carbon dioxide were produced than during the period of deep sleep in the night. There was likewise an excess of 41 c.c. of oxygen consumed and an increase in pulse-rate of 10 beats. This increase in the gaseous metabolism and the pulse-rate persists throughout the whole 31 days of the fast, for on no day was the metabolism during the morning experiment, when the subject was awake, less than during the minimum period of the night experiment, when the subject was in deep sleep. Furthermore, in no instance was an average value secured in the morning experiment with the respiration apparatus which was less than the average value for the whole experiment with the bed calorimeter, when the subject was asleep a part of the time and awake a part of the time.

It will be observed that this increase in the metabolism and in the pulse-rate underwent extreme variations, the range for the carbon-dioxide production being from 33 c.c. on the first night to 11 c.c. on the eighteenth and thirty-first nights, and for the oxygen consumption from 41 c.c. on the first night to 8 c.c. on the tenth night. Nevertheless there was a fairly average value of 17 c.c. for the increase in the carbon-dioxide production, the variation as the fast progressed being not far from this value, except on the twenty-first, twenty-seventh, and twenty-ninth nights. With the oxygen consumption, the variations are much more irregular; these may partly be explained by the difficulties of determining the oxygen consumption exactly, especially when the values for the minimum periods are selected. It is likewise important to note that the oxygen consumption for the morning is invariably higher than not only the minimum during the night but also the average for the whole night.

The increase in the pulse-rate undergoes a much more regular change. On the first 4 mornings of the fast, the pulse-rate is 10 beats higher when the subject is awake than when he is asleep during the night. This increase throughout the fast remains reasonably constant at 8 beats. On but two occasions, *i. e.*, on the twenty-eighth and the thirtieth nights, was the increase only 4 beats.

It is thus clear that, so far as the absolute metabolism is concerned, there is an increase in the period when the subject lay awake on the respiration apparatus over that of the average for the night, when the subject slept for a part or the whole of the time, and particularly over the minimum for the night.

In the post-fasting period, the metabolism on May 16–17 continued to be greater in the morning experiment than in the minimum period for the night experiment. On May 17–18, however, when the subject was in much distress and had consumed a large amount of carbohydrate material, a considerable proportion of which had been retained, the carbon-dioxide production was less in the morning than at night and the oxygen consumption practically the same. There was likewise no

change in the pulse-rate of 84, which was for this subject a very high pulse-rate.

If we consider the respiratory quotients obtained in these experiments, we find that the differences shown in the gaseous metabolism and the pulse-rate practically disappear. This would naturally be expected, since the respiratory quotient indicates the character of the katabolism and there is no reason why this should change essentially during the fasting experiment, regardless of whether the subject was inside the bed calorimeter or lying on the couch with the respiration apparatus. On the first four nights with food we find essentially the same respiratory quotients with both apparatus, while during the fasting nights there is a decrease in the respiratory quotients. The respiratory quotients for the bed-calorimeter experiments are on the average a little lower than those obtained with the respiration apparatus, particularly in the first half of the fast, but this may be due to a slight error in the determination of the residual amount of oxygen in the chamber as a result of faulty measurements of the water-vapor in the chamber air.[1] In any event, we believe that the two series of respiratory quotients are comparable, and it will be seen that they follow essentially the same course throughout the fast. An excellent demonstration of the validity of these comparisons is the fact that, on the two nights with food after the fast, the increased respiratory quotient of 0.80 in the bed-calorimeter experiment was accompanied by a quotient of 0.78 in the experiment with the respiration apparatus the following morning, while on the next night the very high quotient of 0.97 in the bed-calorimeter experiment was followed by a quotient of 0.94 in the experiment with the respiration apparatus. It is thus seen that the respiratory quotient shows essentially no difference in the character of the katabolism as determined by either the bed calorimeter or the respiration apparatus. Furthermore, the fact that the respiratory quotient has the same general value in both instances is an excellent demonstration of the probable trend of this factor, since these quotients were obtained by two methods, within a few hours of each other, so that each figure is an excellent control upon the other.

There are two possible explanations of the differences in the metabolism as measured in the bed calorimeter and with the respiration apparatus. It may be reasonably questioned (1) whether or not the two apparatus measure the respiratory exchange with the same degree of exactness, and (2) whether or not the subject was more active when awake on the respiration apparatus than when asleep in the bed calorimeter.

The measurement of the metabolism by these two apparatus has been carefully compared in a long series of experiments carried out by Mr. T. M. Carpenter. Certain of these comparison tests have already

[1]See page 308.

been published,[1] but a still larger number are being prepared by Mr. Carpenter for early publication. His results give a complete answer to the first criticism, as they show that the measurement of the metabolism by the bed calorimeter is essentially the same as that with the respiration apparatus.

Furthermore, since it has already been shown that the character of the katabolism as indicated by the respiratory quotient was accurately determined by both of these apparatus, it is unreasonable to suppose that there would be any material difference in the measurements of the total metabolism, especially as the two apparatus are constructed on the same principle, *i. e.*, the Regnault-Reiset closed-circuit principle. If one apparatus had been built on the closed-circuit principle and the other upon the open-circuit principle, an error in the measurement of the total ventilation or of the total volume of air passing through the chamber would affect the measurement of the total metabolism without affecting the respiratory quotient. Since the two apparatus were built upon the same principle, however, the possibility of such an error would be very small and any question of a fundamental difference between the results obtained with these two forms of apparatus may therefore be excluded from this discussion.

In considering the second criticism, namely, that there might be a difference in activity when the subject was awake and asleep, it should be pointed out that each experiment in both series was accompanied by a graphic record of the degree of muscular repose of the subject by means of the movable bed previously described.[2] If the records are compared, it will be seen that during the night there were slight movements, as would be natural, since no individual could lie in absolutely the same position for a period of 10 or 12 hours. On the other hand, the record for the experiment with the respiration apparatus in the morning was almost invariably a straight line, showing that the subject had not moved. Mr. Carpenter, who was in charge of the respiration experiments, was of the opinion that the subject was entirely indifferent to the mechanical part of the respiration apparatus and showed not the slightest evidence of muscle tension or apprehension, which might increase the pulse-rate or general muscle tonus. In other words, this subject unquestionably approximated, as nearly as any subject that we have ever experimented with, the conditions described by Johansson[3] as "Vorsätzliche Muskelruhe." It is, furthermore, clear that the average results obtained in the two series of experiments show that as the fast progressed there was a tendency for the values to decrease and essentially at the same rate. This would hardly be expected if the subject were under any great mental strain or anxiety

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. 136, 1910, p. 173.
[2]See page 311.
[3]Johansson, Skand. Archiv f. Physiol., 1898, 8, p. 85.

and it would probably not continue for 31 days. L. frequently said that the experiments were very simple and occasionally remarked that they were quieting and restful. It would appear, therefore, that he was as nearly unaffected by the experimental routine as any person could be, was without anxiety or apprehension, and that there was no evidence of tenseness of muscles.

It thus appears that the only evidence we have of muscular activity during the two series of experiments is the slight activity shown by the kymograph records for the experiments with the bed calorimeter. But such activity would tend to increase the metabolism during the night, when the subject was a part of the time asleep and a part of the time awake, over that when the subject was fully awake on the respiration apparatus. The difference between the results would thus be even greater if the subject were absolutely quiet throughout the night in the bed calorimeter.

Since there was no difference in the methods of measurement and such activity as existed would tend to lessen rather than increase the difference between the results, it seems evident that the difference in the metabolism during the sleeping and waking conditions must be due to the influence of sleep, an influence which has hitherto been disregarded by experimenters. No series of experiments with which we are familiar shows so completely and in such a controlled manner this striking difference in the metabolism between a subject asleep and a subject awake. The pulse-rate is likewise increased during the waking period, being fairly uniform with the increases in the carbon-dioxide production and oxygen consumption. This completely substantiates our view that the pulse-rate gives an admirable index of the internal activity of the body, which largely determines the basal metabolism.

To show more clearly the increase in the metabolism when the subject is awake over the metabolism when he is asleep, the percentage increases in the carbon-dioxide production, oxygen consumption, and pulse-rate are given in table 51 for each day of the experiment. Disregarding the results for the first 4 nights, which are complicated by the influence of food upon the metabolism during the sleeping period, we find on examining the values for the fasting period that there is invariably a considerable percentage increase for the carbon dioxide, oxygen, and pulse-rate. For instance, the percentage increase in the carbon-dioxide production rises as high as 21.7 per cent on the morning following the first night and falls as low as 9.2 per cent on the morning after the ninth night. In general, in the latter part of the fast there was not far from 15 per cent increase in the carbon-dioxide production when the subject was awake over that when he was asleep in the minimum period of the calorimeter experiment. Similar fluctuations were observed in the oxygen consumption, but with hardly the regularity noted in the values for the carbon-dioxide production. During the latter part of

the fast, the average oxygen consumption of the subject awake was not far from 13 to 14 per cent greater than during sleep.

While there is no particular reason to give the increase in the pulse-rate on a percentage basis and expect that it would have a value corresponding to those for the carbon-dioxide production and oxygen consumption, for want of a better comparison at the moment it seems

TABLE 51.—*Increase in metabolism of subject awake as compared with metabolism of subject asleep.*

Date.	Day of fast.	Carbon dioxide.	Oxygen.	Pulse-rate.
1912		*p. ct.*	*p. ct.*	*p. ct.*
Apr. 10–11	.....	—14.7	—12.8	—5.3
11–12	.....	—9.7	—10.6	4.3
12–13	.....	2.0	—4.3	—1.4
13–14	.....	5.2	7.2	14.1
14–15	1st....	21.7	20.9	15.6
15–16	2d.....	16.9	9.1	15.9
16–17	3d.....	14.2	14.1	16.7
17–18	4th....	13.6	13.4	17.2
18–19	5th....	15.3	16.5	13.6
19–20	6th....	13.0	8.1	12.3
20–21	7th....	15.9	10.3	14.3
21–22	8th....	11.9	14.7	12.1
22–23	9th....	9.2	9.8	10.5
23–24	10th....	12.6	4.5	14.5
24–25	11th....	12.9	12.7	13.0
25–26	12th....	11.1	8.1	8.9
26–27	13th....	12.0	15.0	9.3
27–28	14th....	15.5	13.1	13.7
28–29	15th....	15.8	10.5	11.8
29–30	16th....	16.7	15.2	11.5
Apr. 30–May 1	17th....	15.0	18.2	16.3
May 1– 2	18th....	9.8	13.0	9.8
2– 3	19th....	14.4	15.7	14.0
3– 4	20th....	10.7	8.8	13.7
4– 5	21st....	22.3	27.0	15.7
5– 6	22d.....	13.8	11.1	15.7
6– 7	23d.....	14.2	14.6	9.4
7– 8	24th....	15.1	9.9	11.3
8– 9	25th....	15.7	12.9	13.2
9–10	26th....	16.0	11.3	13.0
10–11	27th....	20.6	18.6	12.7
11–12	28th....	13.8	14.5	7.0
12–13	29th....	19.2	12.5	14.5
13–14	30th....	15.5	12.9	7.3
14–15	31st....	10.1	12.2	11.1
16–17	.....	13.7	18.9	20.0
17–18	.....	—2.3	0.5	0.0

advisable to present it in this way. Thus we note here an increase in the pulse-rate ranging from 17.2 per cent on the morning following the fourth night of fasting to as low as 7 per cent after the twenty-eighth night. In the latter part of the fast the pulse-rate is not far from 12 per cent above that found during the sleeping period. There was practically no increase in the carbon-dioxide production, the oxygen

consumption, or the pulse-rate on the last morning of observation following the taking of food, *i. e.*, May 17–18.

An average of the increases for the 31 days shows that the carbon-dioxide production increased 14.7 per cent, the oxygen consumption 13.2 per cent, and the pulse-rate 12.8 per cent. It is perhaps somewhat surprising to note that although there are individual variations on the different days of the fasting experiment and that a given increase in the pulse-rate is not always accompanied by the same percentage increase in the carbon-dioxide production and oxygen consumption, nevertheless the average percentage increase for the carbon-dioxide production, oxygen consumption, and pulse-rate shows a most striking uniformity. While this is not the first time in this laboratory that an attempt has been made to establish a percentage relationship between the pulse-rate and the metabolism, it would appear that in these experiments the increase in metabolism was directly proportional to the increase in the pulse-rate. Under ordinary conditions of laboratory experimentation, in which factors other than those governing the basal minimum metabolism enter, it is hardly probable that this sharp mathematical regularity would obtain, but these closely agreeing results are of considerable significance.

These figures are strikingly at variance with those found by other observers, particularly Johansson[1] and Loewy.[2] The experiments of Johansson are wholly unique, in that he possesses, as probably no other living man does, the power to relax completely his own muscles, thereby lowering his metabolism to a minimum value. His experiments are, however, distinctly vitiated by the fact that his entire series of measurements is based upon the carbon-dioxide output alone, and while considerable care was given to secure regularity in the ingestion of food, it is a fact that the carbon dioxide is not an ideal index of the total katabolism. From the experience in this laboratory with various subjects, in which we have had more or less definite information as to the metabolism of a subject when asleep and when awake, we are perfectly convinced that the metabolism during deep sleep is profoundly affected by the sleeping condition and is much lower than the metabolism when the subject is awake.

METABOLISM PER UNIT OF WEIGHT AND SURFACE.

We have seen in the previous discussion that the most common factors affecting the metabolism—external muscular activity and the ingestion of food—were lacking when the metabolism was studied in this fast, and that the fluctuations which were observed must have been due to other factors; also, that the metabolism was not constant throughout the day. Even under conditions when the subject was

[1]Johansson, Skand. Archiv f. Physiol., 1898, 8, p. 116.
[2]Loewy, Berlin klin. Woch., 1891, p. 434.

lying perfectly quiet, there was still an absence of constancy, for it was found that the metabolism was much lower during the hours of deep sleep at night than in the morning, when the subject was lying upon a couch and connected with the respiration apparatus; also that the metabolism during the evening just prior to the night calorimeter experiment was higher than in the morning. We thus find a definitely established daily rhythm, with the minimum metabolism in the early morning not far from 2 to 4 a. m., a somewhat increased metabolism between 8 a. m. and 9^h 30^m a. m., and a still higher metabolism between 7 p. m. and 8 p. m. As the measurements in all cases were made under conditions when there was muscular repose and no food in the alimentary tract, it is clear that a certain factor not ordinarily considered influences the daily rhythm. This is unquestionably the factor which we may, for want of a better term, designate as "internal muscular work" or cellular activity. When the stimulus to this cellular activity is increased, the subject shows a correspondingly higher metabolism.

As we have already found, the pulse-rate is an admirable index to this tonicity or cellular activity, since the closest correlation has been shown to exist between the pulse-rate and the metabolism. This is perhaps no more strikingly brought out than in comparing the metabolism when the subject was asleep with the metabolism when the subject was awake. While, therefore, the three series of experiments in which the metabolism was determined were not primarily designed to throw light upon the daily rhythm, inasmuch as the main purpose was the study of the alterations in the metabolism as the fast progressed, yet since the data were obtained within the 24 hours, they offer a good demonstration of this diurnal variation in the metabolism and a hint as to its nature. Furthermore, they show the intimate relationship between the pulse-rate and the diurnal variations.

During the 24 hours there was of course no material alteration in body-weight or in body-surface, and hence the data need not be compared upon any special basis other than that of the body as a whole. On the other hand, as the fast progressed there were certain fundamental changes taking place which should be considered in any attempt to interpret the variations in the metabolism noted during the fast. In the first place, the man was obviously losing weight every day. As was pointed out in the discussion of the losses in body-weight of L. during the fast, it would have been possible with a fasting animal to arrange the conditions of the fast so that the loss in weight would have been regular; with a fasting man, however, it was impossible so to control the daily activity, the ingestion of water, the collection of the urine, and the environmental temperature that the loss in weight would follow a mathematical curve; and yet, as has already been shown, it proceeded with a considerable degree of regularity.

As the weight decreases during a fast, there will unquestionably be a change in the body-surface. With certain individuals such loss of weight, either through old age or illness, is not accompanied by a corresponding shrinkage of the skin, and the surface of the skin is consequently wrinkled and hangs in large folds. In general, however, this is not the case; that such a condition certainly did not exist with our fasting subject is clearly shown by the photographs given in plates 4 and 5. Consequently with L. there was undoubtedly a decrease in the radiating body-surface. These factors of decreasing body-weight and body-surface may reasonably be expected to play a role in the metabolism during a long fast, while in a fast of but 24 hours they would be negligible.

Using as indices the changes in the pulse-rate, the blood-pressure, and the pulse-pressure, we find that there was also a considerable variation in the internal muscular activity. Not only do we find variations in the pulse-rate between the conditions of lying asleep and lying awake, but as the fast progressed we find that there were likewise changes from day to day in these values. This is clearly brought out in table 50. On the other hand, the pulse-rate did not continually decrease, for, as was pointed out in a previous discussion of the changes in the pulse-rate, there was a period in which the pulse-rate fell rather rapidly, followed by a period when it remained approximately constant, while toward the end of the fast there was a tendency for the pulse-rate to increase. These changes in the pulse-rate indicate a considerable alteration in the internal muscular activity of the body as the fast continued, thus clearly establishing a factor in metabolism which has heretofore been almost neglected. It is the purpose of this section to examine more closely some of the various factors which affected the metabolism during this prolonged fast.

METABOLISM PER KILOGRAM OF BODY-WEIGHT.

In the attempt to find some unit of comparison, it has long been the custom of many writers to use the kilogram of body-weight, presumably on the ground that with animals differing in size, the larger animal would normally have the greater metabolism. In other words, it has been the custom to assume that the metabolism per kilogram of body-weight is essentially the same for most animals of the same species. As a result of using this unit certain discrepancies have appeared which have been recognized by many writers, but nevertheless this method of comparison is still adhered to and, indeed, individuals of widely varying body-weight have been compared in this way.

If we could determine the composition of the human body, we should certainly find great differences in individuals with different body-weights. With this fasting man we have an ideal condition for studying the metabolism per kilogram of body-weight in that we have an

organism continually losing weight from the beginning to the end of the period of fasting. Furthermore, we can tell with a reasonable degree of accuracy the character of these losses and thus secure some indication as to the probable composition of the human body at the beginning and the end of the fast.

As the fast continues, the changes in the body-weight show a loss of body material. It has been demonstrated, in previous fasting studies,[1] that at the beginning of a fast this loss consists in large part of water, much of which is preformed water. During the first two days of the fast there is unquestionably a further loss of several hundred grams of carbohydrates in the form of glycogen. Subsequently, the loss is of fat; there is also a fairly regular loss of protein from day to day, but after the first few days of the fast the loss is chiefly fat and water. Thus the first 5 kilograms lost from the body in a 31-day fast would certainly be of greatly different composition from the last 5 kilograms lost. The composition of the organism is therefore not the same on the tenth day of fasting, for instance, as on the first day, and varies considerably as to the absolute amounts of fat, carbohydrate, and protein. Consequently, to compare the metabolism on the basis of body-weight is wholly illogical, and although this method of comparison is habitually used by many writers, it is certainly inconsistent with their knowledge of the character of the body losses.

The character of the body material lost may be determined with considerable accuracy. The loss of protein may be computed from the nitrogen found in the urine; the loss of carbohydrate and fat may be computed from the respiratory quotient and the carbon dioxide produced or the oxygen consumed, making due correction for the carbon dioxide produced and oxygen consumed in the combustion of the protein; the amount of water lost may also be found by modern technique. But in considering changes in the metabolism, we are dealing not with the material *lost* from the body, but with the body material remaining in the organism, and to determine the composition of the body at any given period has been found very difficult. While it may be reasonable to attribute any difference in the total metabolism for the first and thirty-first days of the fast to the metabolism that would normally belong to the material lost, this will be true only when we are assured that the living tissue in each case had precisely the same efficiency as to the production of heat and the maintenance of the vital processes.

Certain evidence that has been brought forward in discussing the pulse-rate, and particularly the comparison of the metabolism for a subject lying awake and lying asleep, leads us to believe that there are influences affecting the total heat-production, entirely aside from the organized mass of heat-producing material. Thus we may not say

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 468.

that the subject on the thirty-first day of fasting, with a weight of 2 kilograms less, has the same metabolism as on the twenty-fourth day, for the organism at the end of the fast is living on a higher metabolic plane, as is evidenced by the higher pulse-rate. Consequently a strict comparison of the results on the basis of the metabolism per kilogram of body-weight is precluded.

It is commonly considered that the active heat-forming mass of the body is not found in the fatty tissue nor in the water, but in the organized protoplasmic tissue. If we could assume, for example, that a fasting man when losing weight could lose only fat and water and no organized nitrogenous material, one would expect that as the fast progressed the metabolism per kilogram of body-weight would increase, for while the original mechanism for the production of heat would not alter in any way, the inert material (fat and water) which hitherto contributed to the body-weight, and thus reduced the heat output per kilogram of body-weight, would be removed and the heat output per kilogram should accordingly be increased.

Two important factors militate against this assumption. In the first place, it is impossible for a man to fast for any number of days without a considerable loss of nitrogenous tissue. This may or may not be derived from active protoplasmic tissue, but it certainly is in part a loss of heat-producing tissue. On the other hand, there are known instances when very large amounts of nitrogenous material have been fed to individuals and a considerable proportion of the nitrogen has been retained by the body in some form without apparently changing the value of the heat-producing mechanism, since the heat-production per kilogram of body-weight did not alter. The most notable instance of this is the experiment reported by Mueller[1] in Vienna, who increased the nitrogen content of the body of his subject by 210 grams in 28 days, and yet was unable to obtain the slightest increase in the metabolism per kilogram of body-weight. Apparently the nitrogen added to the body did not enter into the active protoplasmic tissue or contribute to the heat-producing qualities of the body as a whole.

Reference has already been made to several remarkable experiments with dogs carried out by Awrorow, in 1898, in the Imperial Medical Academy in St. Petersburg.[2] These dogs fasted for periods ranging from 16 to 66 days, without water, and remained for 22 hours out of each day inside the Pashutin respiration calorimeter, being catheterized daily. The carbon-dioxide production was measured by absorption in potassium hydroxide and the heat-production by the Pashutin calorimeter. These observations of Awrorow are of such importance in this connection that it seems advisable to reproduce the charts for two of the experiments,[3] *i. e.*, those for dogs No. 2 and No. 3, in which the fast continued for 44 days and 60 days respectively.

[1]Mueller, Zentrlb. f. d. ges. Physiol. u. Path. des Stoff., 1911, **6**, p. 617.
[2]See page 78. [3]See footnote on page 79.

The curves for the body-weight will be recognized as comparable to those given in figure 3 (page 77), although it will be noted that in these two charts the percentage of loss in body-weight is plotted, while in figure 3 the actual body-weights are plotted. The total heat-production and the total carbon-dioxide production for 24 hours fell rapidly for the first 3 days with dog No. 2 and for 7 days with dog No. 3. There-

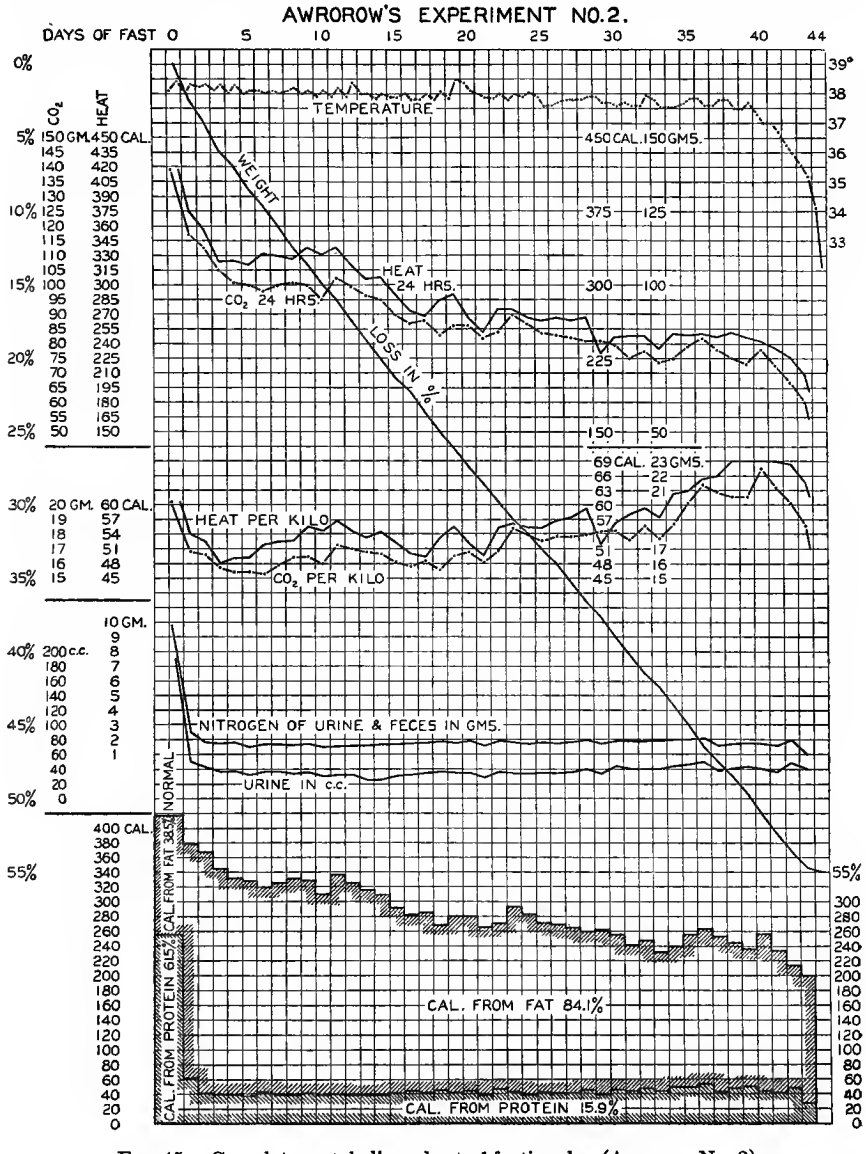


FIG. 45.—Complete metabolism chart of fasting dog (Awrorow No. 2).

The calories from fat may be found by deducting the calories from protein from the total calories as indicated by the scale.

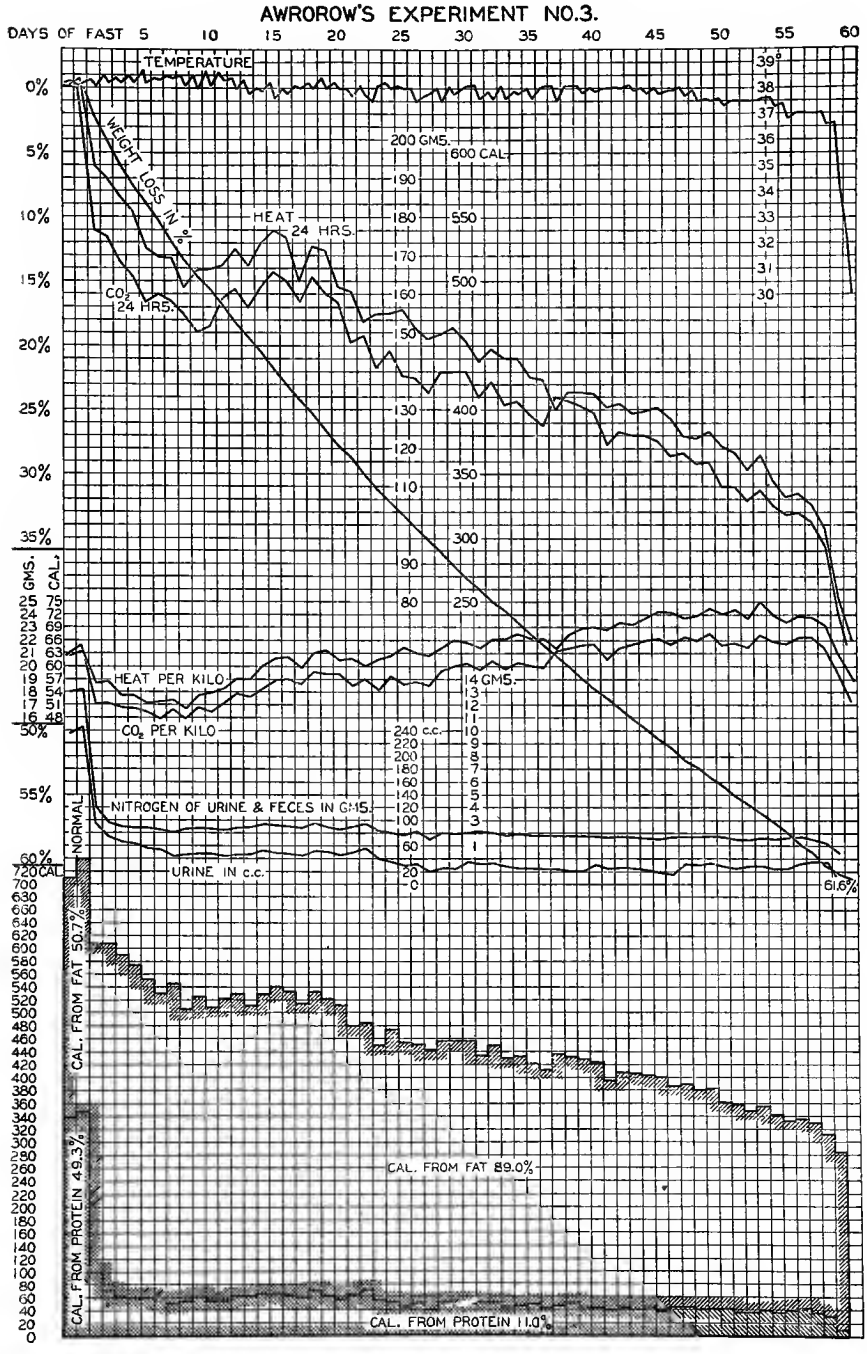


FIG. 46.—Complete metabolism chart of fasting dog (Awrorow No. 3).

The calories from fat may be found by deducting the calories from protein from the total calories as indicated by the scale.

after there was a period of 4 or 5 days of equal production and subsequently a more or less regular fall until the end of the fasting period. It is thus seen that the organisms of these dogs acted not unlike that of our fasting man, that is, the total heat-production and the total carbon-dioxide output decreased with general regularity as the fast progressed. On the other hand, in both experiments, the curves for the carbon-dioxide and heat-production per kilogram of body-weight rise with great regularity throughout the entire fast, falling only on the last 2 or 3 days. Unfortunately, Awrorow does not give the pulse-rate, but from the curves for the temperature given in the upper part of the charts it will be seen that the sharp fall in the last few days of the fast, in both the total heat-production and the heat-production per kilogram of body-weight, was coincidental with a rapidly falling temperature. Since both dogs died, it is probable that they were in a moribund condition in the last day or two of the experiments. On the other hand, it is of interest to note that there was no appearance of a premortal rise in the nitrogen excretion.

Since these dogs had a uniform external muscular activity during their stay in the respiration chamber and probably a uniform internal muscular activity, we deal here only with the relationship between cellular activity and the total body-weight. The increase in the carbon-dioxide and the heat-production per kilogram of body-weight found in these experiments indicates most strongly a resistance to destruction of the heat-producing mechanism in the body which was wholly disproportionate to the losses in body-weight. It is thus seen that in the experiments with these dogs, in which the metabolism was unaffected by muscular work or by the ingestion of food, this distinct conservation of organized material had a marked influence; accordingly, the heat-production per kilogram of body-weight was not constant, but, as a matter of fact, increased as the inert water and fat were lost.

Such ideal conditions for experimenting are obviously impossible with men, and even with Awrorow's dogs there was the disturbing element of falling body-temperature on the last few days, which affected profoundly both the total heat-output and the heat-output per kilogram of body-weight. Since, however, it is the custom of writers to give the heat-production per kilogram of body-weight, it has been necessary to use this basis in computing the metabolism for the experiment with L. in order that the values may be comparable with those of other investigators. The results of these computations are given in tables 52, 53, and 54, which show the metabolism per kilogram of body-weight per minute for the experiments with the bed calorimeter and with the respiration apparatus. In the belief that a question of such fundamental importance should be considered from every standpoint, not only the average results are given for the bed-calorimeter experiments (see table 52), but also the results for the minimum periods obtained with that apparatus (see table 53). The values for the morning experiments with the respiration apparatus are given in table 54.

METABOLISM PER KILOGRAM OF BODY-WEIGHT IN THE CALORIMETER EXPERIMENTS.

Considering first the metabolism as indicated by the average values for the carbon-dioxide production and oxygen consumption during the night in the bed calorimeter (table 52), we find that the carbon-dioxide

TABLE 52.—*Metabolism per kilogram of body-weight and per square meter of body-surface (Meeh) in experiments with L. (Bed calorimeter at night.)*

Date.	Day of fast.	Weight without clothing.[1]	Body-surface.	Average carbon dioxide.			Average oxygen.			Average pulse-rate.	Average body-temperature.
				Per minute.	Per kilogram per minute.	Per square meter per hour.	Per minute.	Per kilogram per minute.	Per square meter per hour.		
1912		*kilos.*	*sq. m.*	*c.c.*	*c.c.*	*gm.*	*c.c.*	*c.c.*	*gm.*		°*C.*
Apr. 10–11[2]	.....	60.37	1.90	224	3.71	13.89	276	4.57	12.45	82	.....
11–12[2]	.....	60.82	1.90	228	3.75	14.14	258	4.24	11.64	76	.....
12–13[2]	.....	61.19	1.91	218	3.56	13.45	252	4.12	11.31	78	.....
13–14[2]	.....	60.87	1.91	180	2.96	11.11	221	3.63	9.92	70	.....
14–15	1st.	59.86	1.88	165	2.76	10.34	212	3.54	9.67	68	.....
15–16	2d.	58.91	1.86	159	2.70	10.07	211	3.58	9.72	66	36.41
16–17	3d.	58.01	1.84	151	2.60	9.67	206	3.55	9.60	62	.....
17–18	4th.	57.22	1.83	150	2.62	9.66	202	3.53	9.46	65	36.55
18–19	5th.	56.53	1.81	143	2.53	9.31	192	3.40	9.09	63	36.58
19–20	6th.	56.01	1.80	134	2.39	8.77	194	3.46	9.24	60	36.44
20–21	7th.	55.60	1.79	135	2.43	8.89	190	3.42	9.10	59	36.42
21–22	8th.	55.18	1.78	137	2.48	9.07	187	3.39	9.00	61	36.55
22–23	9th.	54.74	1.77	134	2.45	8.92	178	3.25	8.62	59	36.50
23–24	10th.	54.25	1.77	130	2.40	8.66	180	3.32	8.72	57	36.64
24–25	11th.	53.94	1.76	128	2.37	8.57	176	3.26	8.57	57	36.80
25–26	12th.	53.64	1.75	129	2.40	8.69	175	3.26	8.57	58	36.85
26–27	13th.	53.48	1.75	126	2.36	8.49	171	3.20	8.38	56	36.62
27–28	14th.	53.22	1.74	120	2.25	8.13	167	3.14	8.23	53	36.30
28–29	15th.	52.92	1.74	117	2.21	7.92	163	3.08	8.03	53	36.43
29–30	16th.	52.40	1.73	117	2.23	7.97	165	3.15	8.17	53	36.40
Apr. 30–May 1	17th.	51.91	1.71	115	2.22	7.93	160	3.08	8.02	52	36.42
May 1– 2	18th.	51.57	1.71	115	2.23	7.93	159	3.08	7.97	52	36.30
2– 3	19th.	51.21	1.70	113	2.21	7.83	158	3.09	7.97	52	36.21
3– 4	20th.	50.97	1.69	114	2.24	7.95	160	3.14	8.11	52	36.51
4– 5	21st.	50.60	1.69	112	2.21	7.81	154	3.04	7.81	54	36.12
5– 6	22d.	50.22	1.68	111	2.21	7.79	154	3.07	7.86	53	36.10
6– 7	23d.	50.00	1.67	112	2.24	7.90	156	3.12	8.01	56	35.98
7– 8	24th.	49.70	1.67	109	2.19	7.69	158	3.18	8.11	55	35.88
8– 9	25th.	49.40	1.66	111	2.25	7.88	153	3.10	7.90	55	36.31
9–10	26th.	49.10	1.65	111	2.26	7.93	159	3.24	8.26	56	.....
10–11	27th.	48.78	1.64	111	2.28	7.98	153	3.14	8.00	57	36.03
11–12	28th.	48.52	1.64	115	2.37	8.26	162	3.34	8.47	59	36.37
12–13	29th.	48.19	1.63	112	2.32	8.10	158	3.28	8.31	58	36.23
13–14	30th.	47.79	1.62	110	2.30	8.00	151	3.16	7.99	58	36.06
14–15	31st.	47.47	1.61	115	2.42	8.42	160	3.37	8.52	57	36.14
16–17[3]	.....	47.37	1.61	124	2.62	9.08	154	3.25	8.20	64	36.79
17–18[3]	.....	48.40	1.64	188	3.88	13.51	194	4.01	10.14	90	37.53

[1]Calculated from the weights observed each morning (see table 2) by adding one-quarter of the loss on each day to the weight obtained on the morning following the night experiment.

[2]The subject had eaten as usual during the day.

[3]The fast was ended with the taking of food on the morning of May 15. The subject ate at intervals throughout the subsequent days.

production per kilogram of body-weight ranged from 3.88 c.c. per minute (the extraordinarily high value found on May 17–18) to 2.19 c.c. per minute on the twenty-fourth day of fasting. Excluding the days with food, the highest value found was on the first night of the fast, namely, 2.76 c.c. per minute. The values show a distinct tendency to fall until the fourteenth day of the fast, with a subsequent essentially constant production of carbon dioxide until the twenty-sixth day. From that time until the end of the fast the carbon-dioxide production tends to be somewhat higher per kilogram of body-weight.

The highest value for the oxygen consumption was found on April 10–11, the first night which the subject spent inside the respiration chamber, *i. e.*, 4.57 c.c. per minute, and the lowest value was 3.04 c.c. on the twenty-first night of the fast. Excluding the periods when food was taken, the highest value, 3.58 c.c., was obtained on the second night of the fast. The oxygen consumption per kilogram of body-weight followed a course which was not unlike that of the carbon-dioxide production, that is, a persistent fall until the fourteenth day of the fast, and thereafter an approximate constancy, with a tendency toward a rise from the twenty-sixth day to the end of the fast.

In the previous comparison of the pulse-rate and the total metabolism, it was found, in the latter part of the fast, that there was a tendency for the pulse-rate to rise which was unaccompanied by an increase in the total carbon-dioxide output and oxygen intake. When the values are computed on the basis of per kilogram of body-weight, the course of the carbon-dioxide and the oxygen is found to be strikingly similar to that of the pulse-rate. At this point, one noticeable anomaly in the otherwise nearly constant relationship between the pulse-rate and the metabolism should be emphasized. On the last night of the fast, the oxygen consumption was 3.37 c.c. per kilogram per minute, while the pulse-rate was 57. On the second night thereafter (namely, on May 16–17) the oxygen consumption was somewhat less, being only 3.25 c.c. per minute, while there was an increase of 7 beats per minute in the pulse-rate. This discrepancy is in part explained by taking into consideration the differences in the calorific value of oxygen with the different respiratory quotients; but we still have a discrepancy which is striking, the only one of any magnitude noted in the long series of observations. Its explanation is not simple.

The average values found throughout the night are complicated by varying conditions of sleeping, waking, and some muscular activity; hence, for the most accurate comparison, use should be made of the values given in table 53, which represent the metabolism per kilogram of body-weight in the minimum periods of the night. With this basis of comparison we find that in certain instances the carbon-dioxide production does not follow closely the oxygen consumption, but the general picture of the progress of the metabolism during the fast is not

altered by these few discrepancies. The pulse-rates given in table 53 should be used with considerable reserve, since it is difficult to select them intelligently on this basis, as the minimum period for the pulse-rate may not have been coincident with the minimum period for either the carbon-dioxide production or the oxygen consumption. It is safe to conclude, however, that the general trend of the pulse-rate is such that its use in this general comparison is not illogical.

TABLE 53.—*Minimum metabolism per kilogram of body-weight and per square meter of body-surface (Meeh) in experiments with L. (Bed calorimeter at night.)*

Date.	Day of fast.	Minimum carbon dioxide.			Minimum oxygen.			Minimum pulse-rate (subject asleep).[1]
		Per minute.	Per kilogram per minute.	Per square meter per hour.	Per minute.	Per kilogram per minute.	Per square meter per hour.	
1912		*c.c.*	*c.c.*	*gm.*	*c.c.*	*c.c.*	*gm.*	
Apr. 10–11[2]	.....	218	3.61	13.52	265	4.39	11.95	76
11–12[2]	.....	217	3.57	13.46	246	4.04	11.10	70
12–13[2]	.....	196	3.20	12.09	235	3.84	10.55	73
13–14[2]	.....	173	2.84	10.67	208	3.42	9.33	64
14–15	1st....	152	2.54	9.53	196	3.27	8.94	64
15–16	2d.....	154	2.61	9.76	208	3.53	9.58	63
16–17	3d.....	148	2.55	9.48	198	3.41	9.22	60
17–18	4th....	140	2.45	9.02	187	3.27	8.76	58
18–19	5th....	137	2.42	8.92	176	3.11	8.33	59
19–20	6th....	131	2.34	8.58	185	3.30	8.81	57
20–21	7th....	132	2.37	8.69	185	3.33	8.86	56
21–22	8th....	135	2.45	8.94	177	3.21	8.52	58
22–23	9th....	131	2.39	8.72	173	3.16	8.38	57
23–24	10th....	127	2.34	8.46	179	3.30	8.67	55
24–25	11th....	124	2.30	8.30	166	3.08	8.08	54
25–26	12th....	126	2.35	8.49	173	3.23	8.47	56
26–27	13th....	125	2.34	8.42	167	3.12	8.18	54
27–28	14th....	116	2.18	7.86	160	3.01	7.88	51
28–29	15th....	114	2.15	7.72	162	3.06	7.98	51
29–30	16th....	114	2.18	7.77	158	3.02	7.83	52
Apr. 30–May 1....	17th....	113	2.18	7.79	154	2.97	7.72	49
May 1– 2	18th....	112	2.17	7.72	154	2.99	7.72	51
2– 3	19th....	111	2.17	7.69	153	2.99	7.71	50
3– 4	20th....	112	2.20	7.81	159	3.12	8.06	51
4– 5	21st....	103	2.04	7.18	137	2.71	6.95	51
5– 6	22d.....	109	2.17	7.65	153	3.05	7.81	51
6– 7	23d.....	106	2.12	7.48	144	2.88	7.39	53
7– 8	24th....	106	2.13	7.48	152	3.06	7.80	53
8– 9	25th....	108	2.19	7.67	147	2.98	7.59	53
9–10	26th....	106	2.16	7.57	151	3.08	7.84	54
10–11	27th....	107	2.19	7.69	145	2.97	7.58	55
11–12	28th....	109	2.25	7.83	145	2.99	7.58	57
12–13	29th....	104	2.16	7.52	152	3.15	7.99	55
13–14	30th....	103	2.16	7.49	147	3.08	7.78	55
14–15	31st....	109	2.30	7.98	148	3.12	7.88	54
16–17[3]	.....	117	2.47	8.56	143	3.02	7.61	60
17–18[3]	.....	176	3.64	12.65	182	3.76	9.51	84

[1]See page 112.

[2]The subject had eaten as usual during the day.

[3]The fast was ended with the taking of food on the morning of May 15. The subject ate at intervals throughout the subsequent days.

The highest value for the carbon-dioxide production during the minimum periods is found, as with the average values, on the last day of the experiment, May 17–18, being 3.64 c.c. per minute. The lowest value is 2.04 c.c. on the twenty-first day of fasting. Disregarding the days with food, we then find the highest value to be 2.61 c.c. on the second day of the fast. There is a general tendency for the carbon-dioxide production per kilogram of body-weight to decrease until the fourteenth day, when there is a marked fall; from that time till the end of the fast the carbon-dioxide production remains essentially constant, with the exception of the low value found on the twenty-first day of fasting and the high values on the twenty-eighth and thirty-first days.

Owing to the many difficulties in determining the oxygen consumption in short periods—difficulties which have already been emphasized[1]—the selection of the minimum periods for the oxygen consumption is not easy and hence we must not expect to find the regularity in these values that we should find in the values for the carbon-dioxide output. The figures given in table 53 have, however, been selected with due care for accuracy. The values ranged from 4.39 c.c. for the first night the subject spent in the chamber to 2.71 c.c. for the twenty-first night. The highest value found for the fasting period was 3.53 c.c., on the second night of the fast. While there is a general tendency for the oxygen values to decrease for the first 15 days of the fast and thereafter to remain essentially constant, one may hardly generalize from such irregular figures.

The pulse-rates, which are taken from table 6, show a regular fall until the fourteenth day, when there is a drop of 3 points. The pulse then stays at the low value of 50 or 51 until the twenty-third day and subsequently shows a definite tendency to increase slowly. The pulse curve is therefore not strictly parallel to that for the carbon-dioxide production per kilogram per minute. The discrepancy previously found in the relationship between the pulse-rate and the average oxygen consumption also appears in the values given here for the minimum periods. Thus, on the last night, the oxygen consumption was 3.12 c.c. per minute and the pulse-rate 54; on the second night with food, the oxygen value was only 0.1 c.c. less or 3.02 c.c., whereas the pulse-rate increased 6 beats per minute. Since it was noted that the minimum values for the body-temperature were not strictly comparable with the metabolism on this basis,we have not included these values in this table.

METABOLISM PER KILOGRAM OF BODY-WEIGHT IN RESPIRATION-APPARATUS EXPERIMENTS.

The difficulties in comparing the values obtained in the bed calorimeter experiments, due to the varying conditions of waking, sleeping, and some muscular activity, disappear when we consider the values obtained in the experiments with the respiration apparatus. In these

[1]See page 324.

experiments we have complete muscular repose and a relatively regular pulse-rate in each group of experimental periods; hence we may properly average the values for the metabolism per kilogram of body-weight from day to day. These values have been computed and are given in table 54, together with the average pulse-rate and body-temperature for each experiment. Of the three series of values compared, this set is probably the most comparable, since we have the greatest muscular repose, controlled graphically by the movable bed, and the subject is always awake. Furthermore the carbon-dioxide production, the oxygen consumption, and the pulse-rate are simultaneously determined.

TABLE 54.—*Metabolism per kilogram of body-weight and per square meter of body-surface (Meeh) in experiments with L. (Respiration apparatus, subject lying in the morning.)*

Date.	Day of fast.	Weight without clothing.	Body-surface.	Carbon dioxide.			Oxygen.			Average pulse-rate.	Average body-temperature.
				Average per minute.	Per kilogram per minute.	Per square meter per hour.	Average per minute.	Per kilogram per minute.	Per square meter per hour.		
1912		*kilos.*	*sq. m.*	*c.c.*	*c.c.*	*gm.*	*c.c.*	*c c.*	*gm.*		°*C.*
Apr. 10–11	.....	60.13	1.89	186	3.09	11.60	231	3.84	10.48	72	.....
11–12	.....	60.53	1.90	196	3.24	12.16	220	3.63	9.92	73	.....
12–13	.....	60.95	1.91	200	3.28	12.34	225	3.69	10.10	72	.....
13–14	.....	60.64	1.90	182	3.00	11.29	223	3.68	10.06	73	.....
14–15	1st.	59.60	1.88	185	3.10	11.60	237	3.98	10.80	74	.....
15–16	2d.	58.68	1.86	180	3.07	11.40	227	3.87	10.46	73	.....
16–17	3d.	57.79	1.84	169	2.92	10.82	226	3.91	10.53	70	.....
17–18	4th.	57.03	1.82	159	2.79	10.30	212	3.72	9.98	68	.....
18–19	5th.	56.37	1.81	158	2.80	10.29	205	3.64	9.71	67	.....
19–20	6th.	55.89	1.80	148	2.65	9.69	200	3.58	9.52	64	.....
20–21	7th.	55.50	1.79	153	2.76	10.07	204	3.68	9.77	64	.....
21–22	8th.	55.08	1.78	151	2.74	10.00	203	3.69	9.77	65	.....
22–23	9th.	54.63	1.77	143	2.62	9.52	190	3.48	9.20	63	.....
23–24	10th.	54.13	1.76	143	2.64	9.58	187	3.45	9.11	63	.....
24–25	11th.	53.88	1.76	140	2.60	9.37	187	3.47	9.11	61	.....
25–26	12th.	53.56	1.75	140	2.61	9.43	187	3.49	9.16	61	.....
26–27	13th.	53.45	1.75	140	2.62	9.43	192	3.59	9.40	59	.....
27–28	14th.	53.15	1.74	134	2.52	9.08	181	3.41	8.92	58	.....
28–29	15th.	52.84	1.73	132	2.50	8.99	179	3.39	8.87	57	.....
29–30	16th.	52.26	1.72	133	2.54	9.11	182	3.48	9.07	58	.....
Apr. 30–May 1	17th.	51.79	1.71	130	2.51	8.96	182	3.51	9.12	57	36.73
May 1– 2	18th.	51.50	1.70	123	2.39	8.53	174	3.38	8.77	56	36.54
2– 3	19th.	51.11	1.70	127	2.48	8.80	177	3.46	8.92	57	36.55
3– 4	20th.	50.93	1.69	124	2.43	8.65	173	3.40	8.77	58	36.85
4– 5	21st.	50.49	1.68	126	2.50	8.84	174	3.45	8.88	59	36.39
5– 6	22d.	50.13	1.67	124	2.47	8.75	170	3.39	8.72	59	36.63
6– 7	23d.	49.96	1.67	121	2.42	8.54	165	3.30	8.47	58	36.24
7– 8	24th.	49.62	1.66	122	2.46	8.66	167	3.37	8.62	59	36.11
8– 9	25th.	49.33	1.66	125	2.53	8.87	166	3.37	8.57	60	36.59
9–10	26th.	49.02	1.65	123	2.51	8.79	168	3.43	8.73	61	.....
10–11	27th.	48.70	1.64	129	2.65	9.27	172	3.53	8.99	62	36.04
11–12	28th.	48.46	1.64	124	2.56	8.91	166	3.43	8.68	61	36.59
12–13	29th.	48.10	1.63	124	2.58	8.97	171	3.55	8.99	63	36.42
13–14	30th.	47.69	1.62	119	2.50	8.66	166	3.48	8.78	59	36.18
14–15	31st.	47.39	1.61	120	2.53	8.78	166	3.50	8.84	60	36.42
16–17	.....	47.12	1.61	133	2.82	9.74	170	3.61	9.05	72	37.12
17–18	.....	48.17	1.63	172	3.57	12.44	183	3.80	9.62	84	37.64

As in the calorimeter experiments, we again find the highest record for the carbon-dioxide production in the last observation of the series, namely, 3.57 c.c. per minute on May 18. The lowest record was 2.39 c.c. per minute on May 2. Disregarding the food days, we find the highest value of 3.10 c.c per minute on April 15, at the end of the first day of fasting. The course of the carbon-dioxide excretion per minute was remarkably regular in the first part of the fast, there being an almost steady fall until the minimum value was reached on May 2; subsequently there was some fluctuation, with a general tendency toward a slight rise.

The highest value for the oxygen consumption during the fasting period (3.98 c.c.) was also found at the end of the first fasting day, and the lowest (3.30 c.c.) was reached on the twenty-third day. The course of the oxygen consumption was in a large measure parallel with that of the carbon-dioxide production, the values showing a slight tendency toward a rise during the last week.

It is of special interest to note that the curve for the pulse-rate prepared on this basis follows with remarkable fidelity the curves for the carbon-dioxide output and oxygen consumption, although the positive differences in the pulse-rate after the tenth day of fasting are very small, the minimum value being 56 and the highest 63. Our recent experience in this laboratory with the photographic registration of the pulse-rate, and particularly with the duration of the pulse-cycle, leads us to believe that our inability to secure registration of the pulse-rate on account of the breaking of the string galvanometer was a loss much greater than was realized at the time of experimentation. The pulse-rate records were made with as great accuracy as would ordinarily be expected with the stethoscope, but the differences are so small that photographic registration would have been most desirable.

Conclusions Regarding the Metabolism per Kilogram of Body-Weight.

In these three series of comparisons it will be seen that the metabolism per kilogram of body-weight fell rapidly during the first half of the fast, then remained constant for a time, and during the last week usually increased slightly. During the entire fasting period the body lost 13.25 kilograms of body material, of which (according to our best estimates) there were 7.33 kilograms of water, 201 grams of carbohydrate, 3,650 grams of fat, and 1,664 grams of protein.[1] It is clear, therefore, that a considerable proportion of the loss, or 87.4 per cent, was made up of material other than protein. It has commonly been believed that the heat-producing organism of the body consists in large part of protein. Under these circumstances, we should expect the heat-production per kilogram of body-weight to increase as the fast progressed, for the total loss of material was much greater in proportion than the loss of active protoplasmic tissue could have been.

[1]See tables 2, 61, 62, and 63.

An examination of the records of the pulse-rate shows, however, that another factor influenced the metabolism, namely, the stimulus to the internal muscular activity or the muscle tonus. The exact nature of this stimulus is difficult at this time to state. Short periods of fasting have shown the presence of acidosis, and an acidosis experimentally induced by giving a carbohydrate-free diet has been found to increase the metabolism.[1] On the other hand, it is known that diabetics tolerate a considerable acidosis without great increase in the metabolism, and the theory has been advanced that the diabetic organism becomes immune to or reacts less vigorously to the stimulus of the acidosis.[2]

While there was unquestionably an acidosis in the 31-day fast, it is highly probable that its influence upon the metabolism must have been practically constant or continually decreasing. Nevertheless, during the last week there was a distinct increase in the pulse-rate, accompanied by a constancy in the metabolism, thus giving striking evidence that the organism was being influenced by some factor of an internal nature. This constancy in the total metabolism may possibly account for the increase in the metabolism per kilogram of body-weight during the last week of the fast, which is similar to the striking increase observed throughout the entire fasting experiments with the dogs studied by Professor Awrorow.

During the first 14 days of the fast there was certainly no constancy between the carbon-dioxide output and the body-weight, for the carbon-dioxide output per kilogram of body-weight was continually decreasing. The fact that for two weeks or more the carbon-dioxide output and the oxygen intake per kilogram of body-weight remained constant should not be taken as a demonstration of an intimate relationship between body-weight and metabolism, since the metabolism had a tendency to increase during the last week. A more intelligent interpretation of the phenomena would be that the total metabolism decreased by virtue of the fact that there was a decrease not only in the size of the heat-producing organism, but in the intensity of the cellular activity, as was indicated by the pulse-rate. When this activity was increased, then the relationship between body-weight and metabolism was entirely obscured. If it were possible to have an experiment in which the pulse-rate remained constant and the change in body-weight was wholly due to inert material, then the values for the heat-production per kilogram of body-weight could logically be compared.

The decrease in the total heat-production as the fast progressed was therefore only in part due to the fact that there was a decrease in the size of the heat-producing organism. With a constant size of organism, as would obtain on any given experimental day during the fast, there still were material differences in the heat production and the intensity of cellular activity which were evidenced by the change in the pulse-rate and by the accompanying noticeable increase in the metabolism.

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. 176, 1912, p. 125. [2]*Ibid.*, p. 134.

While, therefore, the computation of the metabolism on the basis of per kilogram of body-weight is justifiable as a gross index of the probable metabolism of the organism, for the proper interpretation of the values found in this research this method of computation is wholly without avail. It is furthermore of great importance to note that the level of intensity of metabolism in any given organism may have equal, if not indeed greater, influence upon the total metabolism than may the body-weight. It is illogical, therefore, to compare subject A with a pulse-rate of 70 with subject B with a pulse-rate of 70 and assume that the metabolism per kilogram of body-weight should be the same. On the other hand, subject A, with a pulse-rate of 70, will almost invariably have a higher metabolism than with a pulse-rate of 60.

Evidence with regard to the influence of long-continued changes in the body-weight, either as a result of fasting, as a result of diminished diet in obesity cures, or as a result of the increased difference of body material following periods of fasting, are thus far too few to enable us to make general deductions. The enormous addition of nitrogen to the body in the experiments of Mueller[1] without a corresponding increase in the metabolism per kilogram of body-weight suggests a line of research that should prove most profitable. This fundamentally important observation should certainly be repeated and with every control. It is sufficient here only to point out that while custom has sanctioned the general usage of the method of computing the metabolism on the basis of per kilogram of body-weight, such computation can have but little significance when a careful scientific analysis of the results of metabolism experiments is desired.

METABOLISM PER SQUARE METER OF BODY-SURFACE.

Since the heat-production of an animal body varies as to its size, physiologists have long sought to establish some relationship between them. One of the earliest views was that primarily based upon Newton's law of cooling; this is set forth in the simplest form by Bergmann[2] to the effect that the surface of the body is a much more logical factor for considering the needs for heat-production than any other.

Bergmann's original discussion is of interest here:

"Die Oberfläche ist ein einfacher und genau zu ermittelnder Factor für die Wärmeverluste, dessen Werth, zusammengenommen mit der Beschaffenheit dieser Oberfläche (Bedeckung mit Haaren u. s. w.), der Differenz zwischen Temperatur des Thieres und des umgebenden Mediums und Beschaffenheit dieses Mediums (ob es Luft oder Wasser ist) die Wärmeverluste bestimmt.

"Das Volumen des Thieres dagegen wird als ein Maass für die mögliche Warmebildung betrachtet werden können. Gewiss ist in gleichem Volumen sowohl verschiedener Thiere als auch desselben Thieres zu verschiedener Zeit die Wärmebildung sehr verschieden. Aber man wird es nicht gewagt finden,

[1]Mueller, Zentrlb. f. d. ges. Physiol. u. Path. des Stoff., 1911, **6**, p. 617.

[2]Bergmann, Ueber die Verhältnisse der Warmeokonomie der Thiere zu ihrer Grösse., Göttingen, 1848, p. 9.

wenn wir annehmen, dass es für die Wärmebildung ein Maximum gebe, in der Art, dass ein gewisses Quantum animalischer Substanz im lebenden Körper nicht im Stande ist, mehr als ein gewisses Quantum Wärme in einer gegebenen Zeit zu liefern.

"Nun vergrössern oder vermindern sich ja der cubische Inhalt von Körpern und die Ausdehnung ihrer Oberfläche nicht nach demselben Verhältnisse, sondern, wenn wir die einzelnen Dimensionen eines Körpers z. B. sämmtlich im Verhältnisse von 1 zu 2 vergrössern, so wächst die Oberfläche von 1 zu 4 und der cubische Inhalt von 1 zu 8.

"Es ist also entschieden, dass die Thiere, je grösser sie sind, um so weniger Wärme im Verhältniss zu ihrer Grösse zu bilden brauchen, um eine gewisse Erhöhung ihrer Temperatur über die der Umgebung zu gewinnen."

Three decades later, Rubner[1] amplified this idea and presented evidence, secured in researches with his calorimeter, to show that the heat-production was proportional to the body-surface and, indeed, that this law held true with practically all warm-blooded animals. An ingenious method of explaining the apparent relationship between the metabolism and the size of the body-surface was put forth by von Hösslin.[2] Nevertheless Rubner's view has obtained and has been the basis of much discussion since it was first put forth.

The true significance of the apparent relationship between metabolism and body-surface has recently been extensively discussed in connection with the report of a long series of observations on infants recently published from this laboratory,[3] in which it was shown that with infants of approximately normal average weight, height, and age not only was the heat-production per square meter of body-surface by no means constant, but that with atrophic infants the disturbance of the relationship between body-surface and metabolism was far too great to be accounted for by the usual method of explanation, namely, that there was a disturbance in the formula for computing the body-surface. It was pointed out that in all probability the active mass of protoplasmic tissue played a dominant role and that the body-surface was simply a normal function of growth, and with normal conditions of nourishment bore a simple mathematical relationship to the body-weight. According to the recent observations of Dreyer and his associates,[4] the same mathematical relationship obtains between body-weight and various other physiological constants of the body, particularly with the cross-section of the trachea, the aorta, and more particularly the blood volume. While, therefore, the general law of the relationship between the body-surface and metabolism may hold approximately for animals of normal growth and weight, the cause for this relationship is not, we believe, due to Newton's law of cooling, but

[1]Rubner, Zeitschr. f. Biol., 1883, **19**, p. 545.

[2]Von Hösslin, Archiv f. Anat. u. Physiol., 1888, p. 323.

[3]Benedict and Talbot, Carnegie Inst. Wash. Pub. 201, 1914, p. 157.

[4]Dreyer and Ray, Phil. Trans., 1909–1910, **201**, ser. B., p. 133; Dreyer, Ray, and Walker, Proc. Roy. Soc., 1912–1913, **86**, Ser. B, pp. 39 and 56.

to the fact that the heat-producing organism of the body, of which the blood volume is probably a fair index, bears a similar relation to the law of growth as does the body-surface.

It was believed that further information might be secured on this important point in the experiment with the fasting man, and since the heat-production and likewise the oxygen consumption and carbon-dioxide production are discussed by many physiologists on the basis of per square meter of body-surface, such a form of computation has been used here, the values being given in tables 52, 53, and 54. With the fasting man we have a heat-producing organism which is continually decreasing in weight and consequently should decrease in surface. In our calculations it has been assumed that the usual formula for computing the body-surface, namely, that of Meeh, in which the surface is equal to $12.312 \sqrt[3]{W^2}$, holds for each weight as the fast progresses. In former publications from this laboratory, in discussing the metabolism of greatly emaciated patients, particularly diabetics, the contention has been made that there may be a lack of proportion between body-weight and body-surface which is not correctly considered by this formula. But with this fasting man, as has been pointed out previously, and indeed with diabetics studied in this laboratory, there has been no evidence that the skin did not shrink in proportion to the loss in weight, inasmuch as there was no folding of the skin which indicated such a disturbance in the relationship.

Rubner,[1] in his experiments on a fat boy and a thin boy, found that by computing the surface of the thin boy by Bouchard's formula he obtained 10,480 sq. cm. instead of 10,730 sq. cm. as computed by the Meeh formula. With the fat boy the discrepancy was much greater, the Bouchard formula giving 13,522 sq. cm. and the Meeh formula 14,554 sq. cm. In any event the maximum error was only about 7 per cent.

For the sake of argument, it may be considered that on the first day of the fast the body-surface of the subject L. was properly indicated by the Meeh formula, but judging from Rubner's experience with his fat boy, the Meeh formula would give too high a value. As the fast progressed, the error with the Meeh formula would become less and less, until toward the end of the fast it would give the true body-surface. It might then be considered that at the beginning of the experiment the computed value for the body-surface was actually somewhat large and that the computed value for the metabolism per square meter of body-surface would consequently be slightly too small. Nevertheless, the fact that the error can not be more than 7 to 10 per cent should be borne in mind. Furthermore, any correction of this nature will tend to raise the values for the metabolism per square meter of body-surface in the early part of the fast, but will not affect those found for the latter part of the fast.

[1]Rubner, Beiträge zur Ernährung im Knabenalter mit besonderer Berücksichtigung der Fettsucht. Berlin, 1902, p. 40.

With this correction in mind, a comparison may be made of the metabolism found with the bed calorimeter and the respiration apparatus on the basis of per square meter of body-surface.

METABOLISM PER SQUARE METER OF BODY-SURFACE IN CALORIMETER EXPERIMENTS.

Table 52 gives the average metabolism per square meter of body-surface as computed from the values found with the bed calorimeter. On this basis of computation, the carbon-dioxide production ranged from 13.89 grams on the first night inside the respiration chamber to 7.69 grams on the twenty-fourth night. Disregarding the food days, the highest value was 10.34 grams on the first night of the fast. On the last food night of the observation, the carbon-dioxide production was essentially as high as it was on the first 3 nights prior to the fast, namely, 13.51 grams per square meter per hour.

Considering the values for the oxygen consumption per square meter of body-surface, we find that it varied from 12.45 grams on the first night inside the respiration chamber to a minimum of 7.81 grams on the twenty-first night. Again disregarding the food days, the highest value observed is 9.72 grams on the second night of the fast.

If the law holds true that the metabolism per square meter of body-surface remains constant, it is surprising that the variation in the carbon-dioxide production during the fast is so great, *i. e.*, 10.34 grams to 7.69 grams—a decrease of 26 per cent. An approximately similar decrease is noted in the oxygen consumption per square meter of body-surface. Considering the values for both the oxygen consumption and the carbon-dioxide production, we find that the gaseous exchange per square meter of body-surface remained essentially constant from the fifteenth day to the twenty-seventh day of the fast, but in the last 4 days there was a distinct tendency for the gaseous exchange to increase slightly, even on the basis of per square meter of body-surface. While the values were not in complete uniformity with the curve for the pulse-rate, they showed a distinct tendency to follow the same course. No clearly established relationship, however, can be found between the body-temperature and the metabolism per square meter of body-surface.

Since the objections previously cited in reference to comparisons of the average values for the gaseous exchange may apply with equal force in this connection, the gaseous exchange per square meter of body-surface in the selected minimum periods may also be compared on this basis. These values are given in table 53. The carbon-dioxide production ranged from 13.52 grams on the first night inside the chamber to 7.18 grams on the twenty-first night; but if the food days are disregarded, the maximum value was 9.76 grams on the second night of the fast. We find here, however, that there is still a range of 26 per cent in the metabolism per square meter of body-surface, essentially the same as that shown with the average values. The difficulties in

making proper selections for the periods for the oxygen consumption have already been outlined, but we find, from such selections as we have been able to make, that the values per square meter of body-surface ranged from 9.58 grams on the second night of the fast to 6.95 grams on the twenty-first night.

A comparison of the values for the gaseous exchange with the records for the pulse-rate, also given in table 53, must necessarily be made with reserve, owing to the character of the selection as pointed out in the comparison of the values per kilogram of body-weight, but it will be noted that, at least during the first part of the fast, there was a distinct tendency for the metabolism per square meter of body-surface to follow approximately the curve of the pulse-rate. Indeed, even in these minimum selected periods, there was a tendency for the metabolism to rise in the last week of the fast, although this tendency was by no means as pronounced here as in the values given in table 52.

Metabolism per Square Meter of Body-Surface in the Respiration-Apparatus Experiments.

Perhaps the most satisfactory comparison is that of the values obtained with the respiration apparatus in the morning, just after the subject came from the calorimeter chamber, since the conditions were constant in all of the experiments, *i. e.*, simultaneous measurements of the carbon-dioxide production, oxygen consumption, and pulse-rate, when the subject was without food in the alimentary tract and there was complete absence of muscular activity. Under these conditions the values given in table 54 show a range in the carbon-dioxide production per square meter of body-surface from 12.44 grams on May 18 (the last day of observation) to 8.53 grams on the eighteenth day of the fast. Disregarding the values for the food days before and after the fast, the maximum value of 11.6 grams is found at the end of the first fasting day. With the oxygen consumption per square meter of body-surface essentially the same results are found, *i. e.*, a maximum of 10.80 grams at the end of the first fasting day and a minimum of 8.47 grams at the end of the twenty-third day.

These figures indicate that the metabolism per square meter of body-surface tends distinctly to decrease in unison with the pulse-rate during the first half of the fast. In the last 15 days the fluctuation was not so sharply marked, though there was a tendency toward high values in the last week coincidental with the slight tendency to a rise in pulse-rate.

Conclusions regarding the Metabolism per Square Meter of Body-surface.

From a consideration of the fundamental theory regarding the metabolism per square meter of body-surface, it will be seen that the values should be constant, assuming that there is no error in the formula for computing the body-surface from the body-weight. But even if a cor-

rection of 6 or 7 per cent is made according to Rubner's observations, this serves only to increase the high values found in the early part of the fast and to leave unaltered the low values in the latter part, thus making the discrepancy even more striking than before. It is perhaps of more than passing significance that there was a distinct tendency for the metabolism per square meter of body-surface to increase slightly in the last week of the fast, an increase that was accompanied by a slight, though persistent, increase in the pulse-rate. It would appear that this measurable increase in the pulse-rate must be an index of increased cellular activity, which of itself is sufficient to account for the increased total metabolism, irrespective of body-surface or body-weight.

The distinct decrease in the metabolism as the fast progressed, particularly in the first part of the fast, is wholly in conformity with the experience with the fasting subject in Middletown, Connecticut. In the two fasts of 5 and 7 days, respectively, the oxygen consumption and the carbon-dioxide production on the basis of both per kilogram of body-weight and per square meter of body-surface decreased as the fast progressed. Owing to the fact that there were unavoidable differences from day to day in the muscular activity of the continuous sojourn inside the chamber, selected periods, namely, from 1 a. m. to 7 a. m., when the subject was, if not sound asleep, resting quietly in bed, were used for comparison.[1] In the report of these experiments it is clearly shown that in fasting experiments Nos. 71, 73, and 75 there was a pronounced tendency for the metabolism to decrease both per kilogram of body-weight and per square meter of body-surface as the fast progressed. This was noticeably true in the first 15 days of the fast with the subject L., but in the latter part of the fast the metabolism was essentially constant.

With the Middletown subject S. A. B., the pulse-rate showed a tendency to fall regularly throughout the entire fast. With both the subjects S. A. B. and L. there was for the most part a striking uniformity between the pulse-rate and the metabolism measurements. The observations on L. have shown that on any given day the pulse-rate is a strikingly constant index of the total metabolism and to a certain extent gives us a distinct idea of the metabolism as the fast progresses. At the same time it must be borne in mind that the relationship between the pulse-rate and the metabolism is not mathematically so firmly established that it can be said to apply to different individuals. If we consider that L. was continually changing as the fast progressed, and therefore a new organism was being studied each day, it is especially surprising that the pulse-rate is so close an index of the metabolism. This is of particular significance in considering the values for the last week of the fast, for while the rise in the metabolism which accompanied the rise in the pulse-rate was but slight, yet the

[1]See Benedict, Carnegie Inst. Wash. Pub. 77, page 501, table 241.

metabolism stopped falling and the superimposed factor of an altered cellular activity compensated in part for the natural fall in the metabolism which would otherwise have been expected.

SUMMARY OF RESULTS REGARDING THE METABOLISM PER KILOGRAM OF BODY-WEIGHT AND PER SQUARE METER OF BODY-SURFACE.

If we attempt to analyze the prevailing views in regard to the metabolism with the progress of a fast, we find that in the first place it is believed that the metabolism per kilogram of body-weight should rise when the greater part of the loss in weight is made up of inert fat and water. Second, according to the theory of the relationship between the metabolism and the body-surface, the metabolism per square meter of body-surface should remain constant.

So far as the metabolism per kilogram of body-weight is concerned, it is illogical to attribute the same heat-producing value to the body-substance which remains as the body loses weight during the progress of the fast, and this method of computation may not be used advantageously in considering the metabolism of a fasting man. Furthermore, the values for the metabolism per square meter of body-surface show differences of approximately 25 per cent, a result which can not be accounted for in any way by a possible discrepancy in the formula used for computing the body-surface each day. Finally, the evidence is strikingly in favor of the belief that the pulse-rate is an admirable index of the intensity of cellular activity, an activity that plays a very important role in interpreting the total metabolism, entirely irrespective of body-size or body-weight.

An examination of the values appearing in tables 52, 53, and 54 shows that there is a tendency for the metabolism to divide into three periods during the fast. The first period, which extends nearly to the middle of the fast, is characterized by a rapidly falling metabolism and a rapidly falling pulse-rate, the fall in the metabolism being shown not only in the total values, but in the values calculated on the basis of per kilogram of body-weight and of per square meter of body-surface. The second period of approximately 10 days shows a comparatively level metabolism per kilogram and per square meter with an approximately level pulse-rate. The third and last period, or the last week of the fast, shows a general tendency toward an increase in the metabolism, although this was not so apparent in the values for the metabolism per kilogram of body-weight in the minimum periods of the calorimeter experiments. There was also a distinct tendency toward an increase in the pulse-rate in the last week. It thus appears that the striking factor of pulse-rate must continually be reckoned with, even with these conditions of rapidly changing body-weight and body composition. A more exact statement would perhaps be that the intensity of cellular activity plays an important part which is not seriously affected either by changes in the body-weight or the body-surface.

ELIMINATION OF WATER THROUGH LUNGS AND SKIN.

Since the vaporization of water from the lungs and skin is one of the important methods of heat regulation, its determination was formerly given great attention, particularly in the series of 24-hour respiration experiments carried out by Atwater and his associates in Middletown, Connecticut. In the course of these investigations, it became apparent that the water thus vaporized was subject to considerable variation which was, for the most part, irregular in character. Consequently, a knowledge of the water vaporized from the lungs and skin, *per se*, has relatively little value in ordinary metabolism studies, especially with normal subjects, and as such determinations are difficult and expensive, they do not seem justifiable, except so far as it is necessary to note the amount of water vaporized in the calorimeter chamber in order to correct for the heat absorbed in the vaporization. But with the unusual conditions obtaining in the experiments with L., when there was a constantly shrinking skin and at times distinct evidence of a physiological need of water, it seemed desirable to devote the additional time and expense to securing accurate measurements of the water vaporized from the lungs and skin of this man during the time he was inclosed in the calorimeter chamber.

In the discussion of the atmospheric conditions inside the chamber of the bed calorimeter, the values were given in table 44[1] for the amount of water vaporized per hour, with due correction for the water vaporized from the wet-bulb thermometer. This hourly vaporization of water varied from 28.7 grams on the third night of the fast to 13.6 grams on the fifteenth night of the fast. An inspection of all the data in table 44 shows that there was apparently no constant relationship between the amount of water vaporized and the ventilation of the chamber; nor was there a constant relationship between the water vaporized and the chamber temperature, for although the highest average temperature was observed on the night of the highest vaporization of water per hour, yet the first night the subject was inside the chamber the temperature was within 0.1 degree of the maximum, while the vaporization of water was only 25.3 grams. In making a further comparison with the relative humidity, it should be noted that the values for the relative humidity were calculated from the total amount of water vaporized. These computed values, however, agree remarkably well with a number of values obtained by means of a psychrometer in the outgoing air-current, although usually they are a little lower. They may thus be relied upon as indicating the general course of the relative humidity during the fast. An inspection of the values given in table 44 shows that the relationship between the relative humidity and the total vaporization of water was approximately constant. The only scientific use of these figures is in making corrections for the heat required for the vaporization.

[1]See page 321.

It is possible, however, to apportion the vaporization of water between the lungs and the skin by using a method based onthe work of Zuntz, by means of which the water vaporized from the lungs may be estimated.

During the observations of Zuntz and his co-workers, it was established that, under the experimental conditions obtaining, each cubic centimeter of oxygen absorbed from the air was accompanied by a lung ventilation of 21 c.c. In the earlier publication[1] giving the results of the fasting experiments carried out in Middletown, Connecticut, this figure was used for computing indirectly the amount of water-vapor given off from the lungs. In the series of experiments with L. in which the respiration apparatus was used, accurate measurements of the lung ventilation accompanied the determinations of the oxygen consumption, and consequently the relationship between the lung ventilation and the oxygen consumption may be computed for these experiments. From the results of these computations, which are given in table 55, it will be seen that in the extended series of morning experiments the lung ventilation per cubic centimeter of oxygen consumed varied from 34.0 c.c. to 22.6 c.c., these values being materially greater than those obtained in the observations of Zuntz. As the fast progressed, there was a distinct tendency for the lung ventilation per cubic centimeter of oxygen to increase. Observations were also made of the influence of conditions other than that of lying quietly in the morning, such as change of position, time of day, the muscular activity of writing, and the inhalation of oxygen-rich atmospheres, all of which increased the lung ventilation per cubic centimeter of oxygen consumed. This increase was usually not far from 4 to 5 c.c., except that in the last 3 of the 6 experiments with writing, the increase was approximately 9 c.c. over the lung ventilation when the subject was lying quietly in the morning.

Since the relationship between the lung ventilation and the oxygen consumption in the morning respiration experiments with the subject lying quietly is thus well established, it is not unreasonable to assume that the lung ventilation may in turn be obtained for the calorimeter experiments from the oxygen consumed when the subject was inside the respiration chamber. Accordingly, using the oxygen consumption for the night periods and the lung ventilation per cubic centimeter of oxygen consumed for the experiment with the respiration apparatus on the following morning, the values for the ventilation of the lungs have been computed for each of the bed-calorimeter experiments, the results being recorded in table 56.

The air which the subject inhaled while inside the calorimeter chamber obviously contained water-vapor. The amount inhaled may readily be computed from the ventilation of the lungs and the percentage of water-vapor in the air inside the chamber. For instance, it will be seen by reference to the values given in table 44 for the ventilation

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 435.

of the chamber and the water vaporized per hour that the water-vapor in each liter of air on April 10–11 was approximately 11.44 milligrams. Consequently, the water in the air inspired per hour would be equal to 11.44 milligrams multiplied by 415.7, or 4.76 grams. (See columns A and B, table 56). The air expired is assumed to be saturated at

TABLE 55.—*Ventilation of lungs per volume of oxygen in experiments with subject L. (Respiration apparatus.)*

Date.	Day of fast.	Lying (usually 8h 30m a.m. to 9h 30m a.m.).			Lying (usually 7 p.m. to 7h 45m p.m.).		
		Oxygen per minute.	Lung ventilation (observed).		Oxygen per minute.	Lung ventilation (observed).	
			Total per minute.	Per c.c. of oxygen. $\left(\frac{B \times 1000}{A}\right)$		Total per minute.	Per c.c. of oxygen. $\left(\frac{E \times 1000}{D}\right)$
		A	B	C	D	E	F
1912.		*c.c.*	*liters.*	*c.c.*	*c.c.*	*liters.*	*c.c.*
Apr. 11	.....	231	5.80	25.1	...	....	....
12	.....	220	5.66	25.7	...	....	....
13	.....	225	5.61	24.9	...	....	....
14	.....	223	5.14	23.0	...	....	....
15	1st.....	237	5.35	22.6	...	....	....
16	2d.....	227	5.65	24.9	...	....	....
17	3d.....	226	5.71	25.3	...	....	....
18	4th.....	212	5.21	24.6	...	....	....
19	5th.....	205	5.38	26.2	...	....	....
20	6th.....	200	5.11	25.6	...	....	....
21	7th.....	204	5.19	25.4	...	....	....
22	8th.....	203	5.10	25.1	...	....	....
23	9th.....	190	5.17	27.2	...	....	....
24	10th.....	187	4.94	26.4	...	....	....
25	11th.....	187	4.75	25.4	...	....	....
26	12th.....	187	4.94	26.4	193	5.64	29.2
27	13th.....	192	5.03	26.2	[1]195	[1]5.87	[1]30.1
28	14th.....	181	5.00	27.6	190	5.79	30.5
29	15th.....	179	4.94	27.6	189	6.36	33.7
30	16th.....	182	5.44	29.9	190	6.55	34.5
May 1	17th.....	182	5.21	28.6	188	6.30	33.5
2	18th.....	174	5.01	28.8	189	6.33	33.5
3	19th.....	177	5.18	29.3	182	6.16	33.8
4	20th.....	173	5.31	30.7	...	....	....
5	21st.....	174	4.78	27.5	182	6.24	34.3
6	22d.....	170	5.30	31.2	176	6.18	35.1
7	23d.....	165	5.17	31.3	175	6.59	37.7
8	24th.....	167	5.13	30.7	177	6.37	36.0
9	25th.....	166	5.46	32.9	176	6.36	36.1
10	26th.....	168	5.22	31.1	180	6.11	33.9
11	27th.....	172	5.30	30.8	181	6.32	34.9
12	28th.....	166	5.46	32.9	178	6.28	35.3
13	29th.....	171	5.41	31.6	178	6.28	35.3
14	30th.....	166	5.21	31.4	183	6.44	35.2
15	31st.....	166	5.24	31.6	...	....	....
17	.....	170	4.32	25.4	...	....	....
18	.....	183	6.22	34.0	...	....	....

[1]During the period 3h 16m p.m. to 3h 51m p.m., with the subject in the lying position, the observations were: oxygen, 189 c.c.; ventilation per minute, 5.63 liters; ventilation per c.c. of oxygen, 29.8 c.c.

TABLE 55.—*Ventilation of lungs per volume of oxygen in experiments with subject L. (Respiration apparatus)*—Continued.

Date.	Day of fast.	Sitting.[1] Period.	Oxygen per minute. G	Lung ventilation (observed). Total per minute. H	Per c.c. of oxygen. $(\frac{H \times 1000}{G})$ I
1912.			c.c.	*liters.*	c.c.
Apr. 16	2d	4h 00m p.m. to 4h 35m p.m.	244	6.13	25.1
19	5th	4 10 p.m. 4 43 p.m.*	269	8.33	31.0
23	9th	3 52 p.m. 4 28 p.m.	187	6.06	32.4
24	10th	3 58 p.m. 4 57 p.m.	194	6.37	32.8
26	12th	3 13 p.m. 4 11 p.m.	183	5.77	31.5
27	13th	12 14 p.m. 12 48 p.m.	200	6.05	30.3
29	15th	3 23 p.m. 3 56 p.m.*	233	8.60	36.9
May 1	17th	9 31 a.m. 10 04 a.m.*	215	7.12	33.1
4	20th	9 35 a.m. 10 10 a.m.*	208	6.74	32.4
7	23d	3 43 p.m. 4 14 p.m.*	222	8.32	37.5
14	30th	6 32 p.m. 7 02 p.m.*	221	8.77	39.7

[1]Periods indicated by an asterisk were obtained with the subject sitting, writing.

a temperature of 37° C. and, knowing the ventilation of the lungs, it is easy to compute, by means of well-known tables, the amount of water in the air expired from the lungs. For April 10–11 this was found to be 18.07 grams. The amount of water-vapor eliminated from the lungs is therefore the difference between the water in the air inspired and that in the air expired, this being 13.3 grams per hour for April 10–11. The amount of water-vapor eliminated per hour from the lungs and skin, *i. e.*, vaporized inside the calorimeter, on this date was 25.3 grams (see column D), so that the amount of water-vapor given off from the skin would be represented by the difference between columns D and E or 12.0 grams (column F) for April 10–11. The percentage distribution of the water-vapor from the lungs and skin has also been calculated and recorded in this table in columns G and H, and finally (for reference), the relative humidity is given in the last column of the table.

The assumption that the expired air is saturated at 37° C. will unundoubtedly be questioned in the light of the recent work of Loewy[1] and Galeotti.[2] Neither of these researches has, however, stood the test of severe criticism, and while undoubtedly the water-vapor is probably not quite so great as that represented by assuming the air to be saturated at 37° C., nevertheless, for want of firmly established values for this factor, we adhere to the older assumption. It is, furthermore, important to note that any error in this assumption affects only the apportionment of the water vaporization between the lungs and

[1]Loewy and Gerhartz, Biochem. Zeitschr., 1912, **47**, p. 343.
[2]Galeotti, Biochem. Zeitschr., 1912, **46**, p. 173.

the skin for each individual night. The most important comparisons are those made between different days of the fast and with these a considerable error in the assumption might be made without affecting the general deduction.

TABLE 56.—*Water eliminated from the lungs and skin during experiments with L in the bed calorimeter at night. (Amounts per hour.*[1]*)*

Date.	Day of fast.	Ventilation of lungs.[2]	Water in air inspired.[3]	Water in air expired.[4]	Water eliminated.					Relative humidity.
					From lungs and skin.[5]	From lungs. (C−B)	From skin. (D−E)	Proportion.		
								From lungs. $\left(\frac{E\times100}{D}\right)$	From skin. $\left(\frac{F\times100}{D}\right)$	
		A	B	C	D	E	F	G	H	I
1912.		*liters.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*p. ct.*	*p. ct.*	*p.ct.*
Apr. 10–11	.. ....	415.7	4.76	18.07	25.3	13.3	12.0	52.6	47.4	62
11–12	.....	397.8	4.30	17.29	26.3	13.0	13.3	49.4	50.6	62
12–13	.....	376.5	4.12	16.36	26.6	12.2	14.4	45.9	54.1	59
13–14	.....	305.0	3.43	13.26	27.1	9.8	17.3	36.2	63.8	63
14–15	1st...	287.5	2.69	12.50	22.8	9.8	13.0	43.0	57.0	52
15–16	2d...	315.2	3.32	13.70	25.6	10.4	15.2	40.6	59.4	59
16–17	3d...	312.7	3.69	13.59	28.7	9.9	18.8	34.5	65.5	63
17–18	4th..	298.2	2.91	12.96	22.8	10.1	12.7	44.3	55.7	54
18–19	5th..	301.8	2.78	13.12	21.1	10.3	10.8	48.8	51.2	50
19–20	6th..	298.0	2.44	12.95	19.4	10.5	8.9	54.1	45.9	47
20–21	7th..	289.6	2.26	12.59	18.9	10.3	8.6	54.5	45.5	43
21–22	8th..	281.6	2.25	12.24	19.2	10.0	9.2	52.1	47.9	46
22–23	9th..	290.5	2.60	12.63	21.1	10.0	11.1	47.4	52.6	48
23–24	10th..	285.1	2.24	12.39	17.0	10.2	6.8	60.0	40.0	44
24–25	11th..	268.2	2.12	11.66	18.3	9.5	8.8	51.9	48.1	44
25–26	12th..	277.2	2.23	12.05	17.9	9.8	8.1	54.7	45.3	45
26–27	13th..	268.8	2.12	11.68	18.4	9.6	8.8	52.2	47.8	43
27–28	14th..	276.6	2.13	12.02	17.6	9.9	7.7	56.3	43.7	43
28–29	15th..	269.9	1.74	11.73	13.6	10.0	3.6	73.5	26.5	38
29–30	16th..	296.0	2.06	12.87	15.9	10.8	5.1	67.9	32.1	40
Apr. 30–May 1	17th..	274.6	1.88	11.94	15.6	10.1	5.5	64.7	35.3	39
May 1– 2	18th..	274.8	1.92	11.94	16.0	10.0	6.0	62.5	37.5	39
2– 3	19th..	277.8	1.89	12.07	15.5	10.2	5.3	65.8	34.2	39
3– 4	20th..	294.7	2.00	12.81	15.8	10.8	5.0	68.4	31.6	38
4– 5	21st...	254.1	1.71	11.04	14.6	9.3	5.3	63.7	36.3	38
5– 6	22d...	288.3	2.08	12.53	15.7	10.5	5.2	66.9	33.1	40
6– 7	23d...	293.0	2.37	12.74	16.7	10.4	6.3	62.3	37.7	45
7– 8	24th..	291.0	2.24	12.65	16.5	10.4	6.1	63.0	37.0	44
8– 9	25th..	302.0	2.47	13.13	17.5	10.7	6.8	61.1	38.9	46
9–10	26th..	296.7	2.42	12.90	18.0	10.5	7.5	58.3	41.7	46
10–11	27th..	282.7	2.42	12.29	18.7	9.9	8.8	52.9	47.1	48
11–12	28th..	319.8	2.68	13.90	18.9	11.2	7.7	59.3	40.7	46
12–13	29th..	299.6	2.56	13.02	19.3	10.5	8.8	54.4	45.6	46
13–14	30th..	284.5	2.55	12.37	19.7	9.8	9.9	49.7	50.3	49
14–15	31st...	303.4	2.32	13.19	17.9	10.9	7.0	60.9	39.1	42
16–17	.....	234.7	2.08	10.20	20.0	8.1	11.9	40.5	59.5	50
17–18	.....	395.8	3.91	17.20	23.7	13.3	10.4	56.1	43.9	56

[1]For the duration of periods see table 44.

[2]Calculated from the oxygen consumption during the night and the ventilation per volume of oxygen (table 55) observed on the following morning.

[3]Computed by means of the ventilation of the lungs (column A) and the water absorbed per liter of the ventilating air-current, as computed from columns A and B, table 44.

[4]It is assumed that the air expired was saturated and at a temperature of 37° C.

[5]See "Water vaporized per hour," table 44.

The apportionment of the water-vapor between the two paths of excretion presents certain particularly interesting features. On the 4 nights prior to the fast there was a continually decreasing percentage of water excreted from the lungs until the low value of 36.2 per cent was noted on the last night. During the fasting period there was a distinct tendency for the proportion given off from the lungs to increase gradually, and although there were marked irregularities in this increase, particularly on the tenth and fifteenth nights of fasting, yet it may be said that in general the proportion of water vaporized from the lungs became greater and that from the skin less as the fast progressed. The apportionment between the lungs and the skin does not, however, follow any definite law.[1]

Another interesting comparison may be made between the relative humidity and the excretion of water-vapor from the skin. We have existing inside the chamber an essentially constant ventilation and an essentially constant temperature. With a low relative humidity, a high vaporization of water from the skin would be looked for, since one would naturally expect water to vaporize more rapidly from the moist skin of the subject as the air surrounding the body became drier.[2] We find, however, that the opposite is true, since the general course of both the total amounts and the percentage values follows with approximate constancy the values for the relative humidity, the lowest percentage of water excreted from the skin, *i. e.*, 26. 5 per cent on the fifteenth night, being coincidental with the lowest relative humidity. As has been pointed out in a previous section, there was a slight tendency for the relative humidity to increase during the latter part of the fast; this was accompanied in general by an increase in the water vaporized from the skin. It may be inferred, however, that, in general, the body-surface of the man became smaller and the skin less and less moist as the fast progressed and perhaps, in consequence, less capable of losing water.

[1] Nevertheless the wide variations noted by Langlois and Boussaguet (Compt. rend. Soc. Biol., 1912, **72**, p. 967) do not appear in this fasting experiment; the method here employed is, however, fundamentally different from that employed in the French research.

[2] Wolpert, Archiv f. Hygiene, 1902, **41**, p. 301.

CALORIMETRY.

DIRECT CALORIMETRY.

A unique feature of the experiments carried out at Wesleyan University on fasting men was the direct determination of the heat, not only eliminated but produced, by means of a specially designed respiration calorimeter. In these earlier experiments the subject remained the entire fasting period inside the respiration chamber and thus continuous records of the heat output could advantageously be obtained. Knowing that it would be impracticable (and, indeed, unwise) to confine the subject L. inside the respiration chamber for the 31 days of the fast, inasmuch as such confinement would prevent a large number of other important observations, it was decided to make the heat measurements only during the night period.

The significance of the heat measurements in this fasting experiment is altogether different from that of the measurements obtained in the earlier researches at Wesleyan University. In the earlier experiments the primary object was to secure a complete balance of income and outgo and study the transformations of both matter and energy throughout the fast. Consequently, special stress was laid upon these direct heat measurements, the elementary analyses of the urine, and the computations of the amounts of protein, fat, and carbohydrate katabolized; finally a comparison was made of the heat actually measured with that theoretically resulting from the katabolism of the protein, fat, and carbohydrates. Owing to the shortness of the fasts, but little evidence could be obtained regarding the effect of prolonged fasting upon the transformations of matter and energy. In this 31-day fast, however, special emphasis was laid upon the effect of inanition upon the katabolism as the fast progressed. For this purpose, as we have seen, a study of the gaseous exchange at any given hour of each day is amply sufficient, as the influence of the fast upon the gaseous exchange has been found to be essentially the same, regardless of whether it was studied in the morning or in the late afternoon on the respiration apparatus or during the night in the bed calorimeter.

While a continuous measurement of the heat throughout the fast was not practicable, it seemed desirable to have the subject sleep in a chamber fitted with calorimetric appliances[1] and thus simultaneously determine the gaseous exchange and the heat output. Since the whole period of sojourn inside the chamber during the night might vary as to muscular activity and particularly as to wakefulness, any attempt to make a sharp comparison of the results obtained for the various nights of the fast was not to be expected, although subsequently it was found that the remarkable degree of quiet shown by this man enabled

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. 123, 1910.

us to make fairly satisfactory comparisons. It is clear, however, that the direct measurements of the heat output in this particular series of calorimeter experiments were only incidental and not of prime importance in this study. This is particularly fortunate, since, as will be pointed out later, certain unavoidable conditions, particularly with reference to the temperature environment in the calorimeter room, vitiated to a considerable extent the direct measurements of the heat output.

Prior to the arrival of the subject in Boston, the accuracy of the apparatus as to heat measurement had been repeatedly tested[1] by electrical check tests, in which a definite amount of heat was developed with an electric current of known amperage and voltage, and also as to the accuracy of the measurement of the carbon dioxide, water-vapor, and heat produced, as well as oxygen consumed, by burning known amounts of alcohol inside the chamber. It was possible, therefore, to put the subject inside the calorimeter immediately on his arrival at the laboratory and determine the heat output on the several nights preceding the fast.

The calorimeter laboratory is so constructed that the temperature of the room can be kept constant, and during calorimeter experiments it is ordinarily kept at the temperature of the calorimeter. Furthermore, the calorimeter is so made that it normally measures the heat-production with great accuracy, irrespective of whether the environmental temperature is 1° above or below the temperature of the calorimeter. In this fasting experiment, however, a great difficulty was encountered at the outset, in that the subject (who spent the day on a balcony in the calorimeter room) complained so much of cold that it became necessary to increase the temperature of the room throughout the day and to cool it somewhat during the night. Accordingly the calorimeters in the calorimeter laboratory became very much overheated and the measurements of the heat output were inevitably somewhat too large. After the conclusion of the observations on L., a series of check tests was carried out, with conditions as nearly comparable as possible with those existing while the man was in the laboratory, and corrections for the heat output were computed from the results of the tests. It is unnecessary here to discuss the theoretical difficulties of measuring heat with the increased temperature necessary to make the subject comfortable, but we believe the heat measurements as finally recorded here are within 2 or 3 per cent of the actual values. It may be safely said that the measurement is always too great, and the correction would therefore be a minus correction, the probable error being about 2.5 per cent.

It should be borne in mind that the heat production as measured by a respiration calorimeter is made up of several factors. First, a certain

[1]Benedict, Riche, and Emmes, Am. Journ. Physiol., 1910, **26**, p. 1.

amount of heat is given off by radiation and conduction and is absorbed by heat-absorbing pipes through which cold water is passed inside the calorimeter. While this includes the greater portion of the heat measured, there is likewise a considerable elimination of heat due to the vaporization of water from the lungs and skin of the subject. This is measured by weighing the water-vapor in the air-current and making due allowance for the heat of vaporization per gram of water, namely, 0.586 calorie. Furthermore, there should be corrections for any loss of heat through the excretion of urine or feces, and for changes in body-weight. This latter correction is of somewhat more importance in fasting experiments than in ordinary respiration-calorimeter experiments, since the losses in weight are naturally greater. The corrected value thus obtained may properly be called the heat eliminated by the body during the experimental period.

By far the most important correction, however, is that for the changes in the body-temperature, for, as was pointed out in the section in which this factor was considered, a complete comparison of direct and indirect calorimetry, which is always attempted in respiration-calorimeter experiments, necessitates a knowledge of the fluctuations in the body-temperature.[1] While it has been shown that the temperature fluctuations in the various parts of the body follow very closely the temperature fluctuations in the rectum,[2] it is still true that one of the most important and difficult problems in computing the heat production from the heat measured directly by the calorimeter is the possibility of the storage of a considerable amount of heat inside the human body. For example, the body-temperature of a man weighing 60 kilograms falls 0.5° C. This would correspond to a loss of nearly 25 calories, or the total heat production in 20 to 30 minutes of a man asleep; thus, by taking into consideration the temperature changes of the body and the body-weight multiplied by the specific heat (assumed to be 0.83), the amount of heat lost from or stored in the body may be computed and in turn may be subtracted from or added to the heat eliminated. The heat measurement thus corrected is termed the heat produced. In the tabular presentation of our results, we deal usually with the heat-production and not with the heat elimination.

The intelligent use of corrections in the direct measurement of the heat output of man is so difficult that the computation of the heat produced in short periods is highly questionable. An inspection of the heat measurements obtained with our subject during the night shows a lack of uniformity which makes it impracticable to present the heat production in the form of curves, as was done for the carbon dioxide produced and oxygen consumed in figures 41 to 44, but there is distinct evidence of the lowest heat production occurring during the midnight

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. 136, 1910, p. 19.
[2]Benedict and Slack, Carnegie Inst. Wash. Pub. 155, 1911, p. 72.

hours, this being coincident with the minimum respiratory exchange. Of far greater significance is the change in the average heat production throughout the night as the fast progressed.

The subject spent varying lengths of time inside the calorimeter each night, averaging not far from 10 hours, but to make the values comparable the computations are all based either upon the amount of heat produced per hour or per 24 hours. The results of these computations are recorded in table 57, in which the heat produced by the subject in the bed calorimeter at night is given on the basis of the total

TABLE 57.—*Heat produced by subject L. during experiments in the bed calorimeter at night.*

Date.	Day of fast.	Per hour.		Computed to basis of 24 hours.	
		Total.	Per kilogram of body-weight.	Total.	Per sq. meter of body-surface (Meeh).
1912.		*cals.*	*cals.*	*cals.*	*cals.*
Apr. 10–11[1]	.....	83.4	1.38	2002	1054
11–12[1]	.....	81.0	1.33	1944	1023
12–13[1]	.....	74.9	1.22	1798	941
13–14[1]	.....	68.3	1.12	1639	858
14–15[1]	1st.....	64.0	1.07	1536	817
15–16	2d.....	64.3	1.09	1543	830
16–17[1]	3d.....	64.1	1.10	1538	836
17–18	4th.....	63.1	1.10	1514	827
18–19	5th.....	57.6	1.02	1382	764
19–20	6th.....	58.1	1.04	1394	774
20–21	7th.....	56.7	1.02	1361	760
21–22	8th.....	58.6	1.06	1406	790
22–23	9th.....	53.1	.97	1274	720
23–24	10th.....	53.5	.99	1284	725
24–25	11th.....	52.4	.97	1258	715
25–26	12th.....	51.9	.97	1246	712
26–27	13th.....	51.7	.97	1241	709
27–28	14th.....	50.6	.95	1214	698
28–29	15th.....	47.1	.89	1130	649
29–30	16th.....	46.1	.88	1106	639
Apr. 30–May 1	17th.....	45.7	.88	1097	642
May 1– 2	18th.....	46.5	.90	1116	653
2– 3	19th.....	47.9	.94	1150	676
3– 4	20th.....	46.9	.92	1126	666
4– 5	21st.....	44.0	.87	1056	625
5– 6	22d.....	45.7	.91	1097	653
6– 7	23d.....	45.6	.91	1094	655
7– 8	24th.....	45.3	.91	1087	651
8– 9	25th.....	44.1	.89	1058	637
9–10[1]	26th.....	47.8	.97	1147	695
10–11	27th.....	46.0	.94	1104	673
11–12	28th.....	46.2	.95	1109	676
12–13	29th.....	46.9	.97	1126	691
13–14	30th.....	47.1	.99	1130	698
14–15	31st.....	47.0	.99	1128	701
16–17	.....	46.1	.97	1106	687
17–18	.....	62.6	1.29	1502	916

[1]The heat measured during the night experiments on the days noted has been corrected only for the change in body-weight and not for change in body-temperature.

amount per hour, the amount per kilogram per hour, the total amount per 24 hours, and the amount per square meter of body-surface per 24 hours. With the exception of the first few days, the values given are all for heat produced, *i. e.*, the heat measured by the apparatus corrected for both change in body-weight and change in body-temperature. For those nights on which the body-temperature was lacking, the correction is made only for changes in body-weight, *i. e.*, only the heat eliminated is given.

Before discussing the values in table 57, it should be noted that the figures are not strictly comparable, since, as has already been stated, the muscular activity was not absolutely uniform. The kymograph records show that the subject was remarkably quiet, so that no great correction would be necessary for differences in the muscular activity; but unquestionably the amount of sleep varied and, as has already been shown, the influence of sleep *per se* upon the metabolism should be taken into consideration. Nevertheless, the values are determined under sufficiently uniform conditions to justify their comparison if it be clearly understood that there is a reasonably constant error of technique due to the extreme heat of the calorimeter laboratory, a certain lack of uniformity in the muscular activity, and, finally, material differences in the amount of time spent by the subject awake or asleep.

The total heat produced varied from a maximum of 83.4 calories per hour on the first night inside the chamber to a minimum of 44.0 calories per hour on the twenty-first night of fasting. When the heat production is computed on a 24-hour basis, a maximum is obtained of 2,002 calories and a minimum of 1,056 calories. The steady fall in the total heat production per hour during the first 2 weeks of fasting, followed by a period of approximately constant output of heat with a slight tendency towards an increase in the last week, is consistent with our observations on metabolism as recorded in the earlier chapters of this book.

As a concession to those writers who are wont to consider the heat production on the basis of per kilogram of body-weight and per square meter of body-surface, both values have been computed and included in table 57. The heat per kilogram of body-weight per hour varies from a maximum of 1.38 calories on the first night inside the chamber to a minimum of 0.87 on the twenty-first night of the fast. Even on this basis there is a distinct fall in the heat production per kilogram of body-weight during the first two weeks, with an approximately constant level for a short period and then a distinct tendency to increase during the last week of the fast.

On the basis of per square meter of body-surface in 24 hours, the heat production varied from a maximum of 1,054 calories on the first night inside the chamber to a minimum of 625 calories on the twenty-first night of the fast. On the first 4 nights the heat production is clearly affected by the previous ingestion of food on the evening before,

but during the strictly fasting period we have a variation ranging from 836 calories per 24 hours on the third night of the fast to a minimum of 625 calories per 24 hours on the twenty-first night, a variation of somewhat more than 25 per cent. Even on this basis, when presumably the values should all be constant, there is a distinct falling off in value during the first 2 weeks of fasting, followed by a period of approximately constant heat production per square meter, with a distinct rise in the values in the last week of fasting.

It is thus clear that the deductions drawn from an inspection of the data for the respiratory exchange in the foregoing chapters apply equally well to the total heat production as measured in the respiration calorimeter, even admitting the discrepancies outlined previously. The general picture is by no means obscured by the assumptions made, this showing that the influence of fasting *per se* upon not only the total heat production but the heat production per kilogram of body-weight and per square meter of body-surface was fully in accord with the influence of fasting upon the respiratory exchange. It seems unwise, however, to dwell further upon these results of the heat measurements and thereby possibly ascribe to them too much importance. The errors cited bring them clearly out of the sphere of accurate physiological experimentation and make them of value only for subsidiary evidence. For a more careful and certainly more nearly exact consideration of the heat production under different conditions during the fast, we must resort to the method of indirect calorimetry.

INDIRECT CALORIMETRY.

Second only in value to accurate direct measurements of the heat output from the body is the method of so-called "indirect calorimetry," this being an excellent substitute for the difficult and costly direct calorimetry. By considering the nitrogenous material excreted in the urine and the amount of carbon dioxide produced and oxygen absorbed, it is possible to apportion the katabolism among the various body constituents, these being chiefly protein, fat, and carbohydrate, and to compute (from the well-known heats of combustion of these constituents) the amount of heat liberated in the process of their disintegration.

Several methods of computing the heat production thus indirectly have been employed by various writers. Perhaps the most elaborate and fundamentally exact is that based upon 24-hour studies of the gaseous exchange, such as were made with the respiration calorimeter formerly used at Wesleyan University. The elementary analyses of food, feces, and urine, and the direct determination of the oxygen absorbed and the carbon dioxide produced gave data for computing, by simultaneous equations,[1] the amounts of protein, carbohydrate (glycogen), fat, and water participating in the metabolism. From these data and the heats of combustion of the various body constituents and of the urine and feces, the total energy production could be accurately

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, pp. 36 and 452.

computed. Such computed energy transformations agreed remarkably well with the direct measurements of the heat produced per 24 hours.

When, as is frequently the case, an exact knowledge of the various amounts of carbohydrate, fat, and protein disintegrated is not of particular significance, it is possible to secure the heat-production indirectly from the measurements of the carbon dioxide produced and the oxygen consumed without computing the different constituents oxidized. Zuntz has computed most carefully the calorific equivalents of both oxygen and carbon dioxide and assumes that for every liter of oxygen absorbed in normal metabolism a definite number of calories must have been developed. The calorific value of carbon dioxide varies greatly, the variations depending upon whether the carbon dioxide is produced by the combustion of carbohydrate or of fat. Thus, with every gram of carbon dioxide resulting from the oxidation of carbohydrate 2.57 calories of heat are produced, and from the oxidation of fat 3.41 calories. On the other hand, the calorific equivalent of oxygen does not fluctuate so widely, for when carbohydrate is burned, 3.53 calories of heat are developed for every gram of oxygen consumed, and when pure fat is burned, 3.28 calories are produced. It is therefore only necessary to determine the carbon-dioxide production and oxygen consumption very exactly, and from the respiratory quotient and the absolute amount of either oxygen or carbon dioxide it is possible to compute the heat production by using the calorific value for the oxygen or the carbon dioxide.

With the Zuntz-Geppert apparatus, oxygen is determined as accurately as is carbon dioxide, and since the calorific value of oxygen remains essentially constant, Zuntz has regularly used the oxygen measurements and multiplied by the calorific equivalent of oxygen. In connection with his researches on the physiology of marching, published with Schumburg, Zuntz[1] worked out a table which gave the respiratory quotients and calorific equivalents of oxygen with varying proportions of fat and carbohydrate in the material oxidized.

A more difficult matter is the determination of the calorific equivalent of oxygen when protein is burned. Loewy[2] has correctly pointed out that in experiments of short duration it is justifiable to compute the heat production indirectly by using the carbon-dioxide output and oxygen intake without taking into account the protein disintegration, since the protein disintegration may or may not be simultaneous with the nitrogen excretion. As a matter of fact, the calorific equivalents of oxygen and carbon dioxide when protein is burned are not greatly different from those for either fat or carbohydrate; and furthermore, since the protein usually furnishes only about 15 per cent of the total energy, the error in thus neglecting the protein is extremely small, especially for short experiments.

[1]Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.
[2]Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, 4 (1), p. 281.

On the other hand, in considering the results of long experiments, it is not justifiable to neglect the protein entirely. As the result of a large number of experiments made by Rubner and by Zuntz and his associates, a certain number of standard figures regarding the combustion of protein may be used with considerable confidence. Thus, they have definitely established that 1 gram of nitrogen in the urine corresponds to a heat production of 26.51 calories as a result of the oxidation of protein. Furthermore, Zuntz has computed that for each gram of nitrogen in the urine 5.91 liters of oxygen are absorbed and 4.75 liters of carbon dioxide are produced. These values were obtained from experiments on animals which were fed a diet of meat only. The method of computing the energy from protein by making a special computation for the energy accompanying the nitrogen in the urine was employed by Zuntz[1] in computing the energy output from the values found with the fasting subjects Cetti and Breithaupt.

Williams, Riche, and Lusk[2] have also made use of these values for computing the heat production even in short periods, and in accordance with the computations of Loewy have calculated the non-protein respiratory quotient by deducting the carbon dioxide and oxygen apportioned to the protein oxidation from the total measured amounts of these gases. Using this non-protein respiratory quotient and Zuntz and Schumburg's table, they have computed the energy of fat and carbohydrate. The total urinary nitrogen multiplied by 26.51 gave the energy value for protein.

Magnus-Levy[3] and Loewy,[4] in discussing the indirect method of calculating the heat output, emphasize the fact that the computation gives accurate results only when the oxidation in the body proceeds along normal lines. Recognizing the fact that there is a not inconsiderable disturbance of the intermediary metabolism during prolonged fasting, due in part to the excretion of large amounts of ammonia and the formation of β-oxybutyric acid, Grafe[5] has attempted to compute the heat production by making numerous corrections, some of which are certainly based upon premises not beyond question.

After a careful consideration of the various methods for computing indirectly the energy production from the gaseous exchange and the urinary excretion of nitrogen, and taking into account all the possible errors and the weight of the errors in the different determinations, it seemed most advantageous to use in our calculations the method recommended by Magnus-Levy, in which the heat output can be directly computed by using the calorific equivalent of oxygen for

[1]Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol. u. f. klin. Med., 1893, **131**, Supp., p. 208.

[2]Williams, Riche, and Lusk, Journ. Biol. Chem., 1912, **12**, p. 357.

[3]Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, **1**, p. 217.

[4]Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4** (1), p. 281.

[5]Grafe, Zeitschr. f. physiol. Chem., 1910, **65**, p. 21.

the various respiratory quotients. Magnus-Levy[1] computed that if 0.031 calorie per liter is deducted from the calorific equivalent of oxygen, the correction for the energy requirement of protein is thereby made, assuming that only about 15 per cent of the total energy of the day is obtained from protein. If the energy from protein is 30 per cent of the daily quota, the correction would be 0.064 calorie. Thus, according to the table of Zuntz and Schumburg, a non-protein respiratory quotient of 0.738 would correspond to a calorific equivalent of oxygen equal to 4.724 calories; but with a respiratory quotient of 0.738 and a division of the energy between 30 per cent of protein and 70 per cent of fat, the calorific equivalent would be, according to Magnus-Levy, 4.660 calories or 0.064 calorie less.

A computation of the energy which should be apportioned to protein during the calorimeter period showed that in general about 20 per cent of the total energy was derived from protein. Making use of this value and computing the correction so that it may be used with carbon dioxide instead of oxygen, we have employed a correction of 0.057 calorie per liter of carbon dioxide. Hence, by deducting 0.057 calorie from the calorific equivalent of carbon dioxide as presented in the table given by Benedict and Talbot,[2] the heat output is rapidly calculated and the correction for the difference in the factor due to the energy from protein is simultaneously made. Since the computations for energy are chiefly for purposes of comparison as the fast progresses, and since we do not have the nitrogen output during the first nights of the fast, the value 0.057 has been used for computing the entire series. The results are given in table 58.

As was pointed out in discussing the values found for the gaseous exchange, at least three bases for comparison may be used:

First, a comparison of the heat output during the bed-calorimeter experiments has a distinct advantage, since the experimental periods were so long, being approximately 10 hours.

Second, as there was irregularity in the amount of activity inside the bed calorimeter, and also a difference in the time spent in sleep, it is distinctly advantageous to select periods throughout the night in which there was a minimum amount of activity and compare the minimum metabolism for the various nights as the fast progressed.

Finally, it is probable that no periods throughout the day are so comparable as the morning respiration experiments, in which the conditions were ideal, as the subject lay perfectly quiet upon the couch and always awake; consequently, comparisons can be made between the results obtained with the respiration apparatus and with the bed calorimeter.

[1]See Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, 4 (1), p. 281; also, Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, 1, p. 207.

[2]Benedict and Talbot, Carnegie Inst. Wash. Pub. 201, 1914, p. 29.

TABLE 58.—*Heat production (indirect) computed from the gaseous exchange in experiment with subject L. in the lying position.*

Date.	Day of fast.[1]	Bed calorimeter (night).[1]					
		Average basis.				Minimum basis.	
		Carbon dioxide per minute. A	Respiratory quotient. B	Calorific equivalent of carbon dioxide. C	Heat per 24 hours. (A×C×1440) D	Carbon dioxide per minute. E	Heat per 24 hours. (E×C×1440) F
1912.		*liter.*		*cals.*	*cals.*	*liter.*	*cals.*
Apr. 10–11[2]	.....	0.224	0.81	5.885	1898	0.218	1847
11–12[2]	.....	.228	.88	5.511	1809	.217	1722
12–13[2]	.....	.218	.86	5.612	1762	.196	1584
13–14[2]	.....	.180	.81	5.885	1525	.173	1466
14–15	1st.	.165	.78	6.066	1441	.152	1328
15–16	2d.	.159	.75	6.262	1434	.154	1389
16–17	3d.	.151	.73	6.401	1392	.148	1364
17–18	4th.	.150	.74	6.331	1367	.140	1276
18–19	5th.	.143	.75	6.262	1289	.137	1235
19–20	6th.	.134	.68	6.637	1281	.131	1252
20–21	7th.	.135	.71	6.549	1273	.132	1245
21–22	8th.	.137	.73	6.401	1263	.135	1244
22–23	9th.	.134	.75	6.262	1208	.131	1181
23–24	10th.	.130	.72	6.474	1212	.127	1184
24–25	11th.	.128	.72	6.474	1193	.124	1156
25–26	12th.	.129	.73	6.401	1189	.126	1161
26–27	13th.	.126	.74	6.331	1149	.125	1140
27–28	14th.	.120	.72	6.474	1119	.116	1081
28–29	15th.	.117	.71	6.549	1103	.114	1075
29–30	16th.	.117	.71	6.549	1103	.114	1075
Apr. 30–May 1	17th.	.115	.72	6.474	1072	.113	1053
May 1– 2	18th.	.115	.72	6.474	1072	.112	1044
2– 3	19th.	.113	.71	6.549	1066	.111	1047
3– 4	20th.	.114	.71	6.549	1075	.112	1056
4– 5	21st.	.112	.73	6.401	1032	.103	949
5– 6	22d.	.111	.72	6.474	1035	.109	1016
6– 7	23d.	.112	.72	6.474	1044	.106	988
7– 8	24th.	.109	.69	6.637	1042	.106	1013
8– 9	25th.	.111	.72	6.474	1035	.108	1007
9–10	26th.	.111	.70	6.637	1061	.106	1013
10–11	27th.	.111	.72	6.474	1035	.107	998
11–12	28th.	.115	.71	6.549	1085	.109	1028
12–13	29th.	.112	.72	6.474	1044	.104	970
13–14	30th.	.110	.72	6.474	1025	.103	960
14–15	31st.	.115	.72	6.474	1072	.109	1016
16–17[2]	.....	.124	.80	6.001	1072	.117	1011
17–18[2]	.....	.188	.97	5.165	1398	.176	1309

[1]For duration of periods, see table 44.

[2]On the days preceding and following the fast the night experiments were made after the ingestion of food.

TABLE 58.—*Heat production (indirect) computed from the gaseous exchange in experiment with subject L. in the lying position*—Continued.

Date.	Day of fast.	Respiration apparatus (morning).[1]							
					Heat.				
					Per hour.		Per 24 hours.		Increase (awake) above night minimum (asleep) on 24-hour basis (L—F).
		Carbon dioxide per minute.	Respiratory quotient.	Calorific equivalent of carbon dioxide.	Total (G×I×60).	Per kilogram of body-weight.	Total (J×24).	Per square meter of body-surface.	
		G	H	I	J	K	L	M	N
1912.		*liter.*		*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Apr. 10–11[2]	.....	0.186	0.81	5.885	65.7	1.09	1577	834	−270
11–12[2]	.....	.196	.89	5.462	64.2	1.06	1541	811	−181
12–13[2]	.....	.200	.89	5.462	65.5	1.07	1572	823	− 12
13–14[2]	.....	.182	.82	5.827	63.6	1.05	1526	803	60
14–15	1st.	.185	.78	6.066	67.3	1.13	1615	859	287
15–16	2d.	.180	.79	6.005	64.9	1.11	1558	838	169
16–17	3d.	.169	.75	6.262	63.5	1.10	1524	828	160
17–18	4th.	.159	.75	6.262	59.7	1.05	1433	787	157
18–19	5th.	.158	.77	6.130	58.1	1.03	1394	770	159
19–20	6th.	.148	.74	6.331	56.2	1.01	1349	749	97
20–21	7th.	.153	.75	6.262	57.5	1.04	1380	771	135
21–22	8th.	.151	.74	6.331	57.4	1.04	1378	774	134
22–23	9th.	.143	.75	6.262	53.7	.98	1289	728	108
23–24	10th.	.143	.76	6.196	53.2	.98	1277	726	93
24–25	11th.	.140	.75	6.262	52.6	.98	1262	717	106
25–26	12th.	.140	.75	6.262	52.6	.98	1262	721	101
26–27	13th.	.140	.73	6.401	53.8	1.01	1291	738	151
27–28	14th.	.134	.74	6.331	50.9	.96	1222	702	141
28–29	15th.	.132	.74	6.331	50.1	.95	1202	695	127
29–30	16th.	.133	.73	6.401	51.1	.98	1226	713	151
Apr. 30–May 1	17th.	.130	.71	6.549	51.1	.99	1226	717	173
May 1– 2	18th.	.123	.71	6.549	48.3	.94	1159	682	115
2– 3	19th.	.127	.72	6.474	49.3	.96	1183	696	136
3– 4	20th.	.124	.72	6.474	48.2	.95	1157	685	101
4– 5	21st.	.126	.73	6.401	48.4	.96	1162	692	213
5– 6	22d.	.124	.73	6.401	47.6	.95	1142	684	126
6– 7	23d.	.121	.73	6.401	46.5	.93	1116	668	128
7– 8	24th.	.122	.73	6.401	46.9	.95	1126	678	113
8–9	25th.	.125	.75	6.262	47.0	.95	1128	680	121
9–10	26th.	.123	.73	6.401	47.2	.96	1133	687	120
10–11	27th.	.129	.75	6.262	48.5	1.00	1164	710	166
11–12	28th.	.124	.75	6.262	46.6	.96	1118	682	90
12–13	29th.	.124	.73	6.401	47.6	.99	1142	701	172
13–14	30th.	.119	.72	6.474	46.2	.97	1109	685	149
14–15	31st.	.120	.72	6.474	46.6	.98	1118	694	102
16–17[2]	.....	.133	.78	6.123	48.9	1.04	1174	729	163
17–18[2]	.....	.172	.94	5.290	54.6	1.13	1310	804	1

[1]Duration of period was usually $8^h\ 30^m$ a. m. to $9^h\ 30^m$ a. m.
[2]The subject was without breakfast.

The results of the computation of the heat output on these three bases are given in table 58, in which are recorded first the heat output per 24 hours, computed on the average values obtained with the bed calorimeter throughout the night; second, the heat per 24 hours computed from results obtained in the selected minimum periods during the night; and third, the heat per 24 hours computed from the results obtained with the respiration apparatus; and finally, the heat per kilogram of body-weight per hour and per square meter of surface per 24 hours computed from the observations with the respiration apparatus. These values were computed from the total carbon-dioxide output and the calorific equivalent of carbon dioxide, corrected for the difference due to the energy from protein, as stated previously, by deducting 0.057 calorie per liter.

The average heat output on the 24-hour basis ranged from 1,898 calories on the first night inside the chamber to a minimum of 1,025 calories on the thirtieth night. Since the results obtained during the first 4 nights in the chamber were complicated by the previous ingestion of food, particularly the night of April 10–11, when a large amount of protein was taken in the evening meal, the results obtained for the fasting period are more properly compared. The highest value for the fasting period is 1,441 calories on the first night and the lowest value is 1,025 calories on the thirtieth night. It is thus seen that there was a steady decrease in the total heat output as the fast progressed, although from the twenty-first to the thirty-first day the heat production showed a tendency towards constancy.

Using only the minimum periods during the night, we find a maximum value of 1,847 calories on the first night in the chamber and a minimum of 949 calories on the twenty-first night. For the fasting period, the values ranged from 1,389 calories on the second night of the fast to 949 calories on the twenty-first night. Here, again, it will be observed there was a steady fall in the heat production to about the twenty-first day of the fast, and from that time the heat output showed a tendency to remain approximately constant for the last 10 nights.

Any possible criticisms of the comparisons of the minimum bed-calorimeter periods disappear in comparing the values found with the respiration apparatus. Here we find that the heat production ranged from 1,615 calories on the morning following the first night of the fast to 1,109 calories on the morning following the thirtieth night of the fast. There is a distinct tendency for the heat production to fall progressively until the twenty-third day, and from that time on it remains more or less a constant.

Of special importance in connection with this comparison is the fact that on the first 3 nights the heat production in the bed-calorimeter experiments was greater than in the experiments with the respiration apparatus the following morning. This was undoubtedly due to the

heavy evening meal, which, except on the night of April 13–14, contained a not inconsiderable amount of protein. The heat production on the morning following the fourth night with food was 1 calorie greater than the average heat output during the night, and the heat production, from that time on, was invariably larger in the morning experiments than during the night. Naturally, when we use the values computed for the minimum periods during the night, this increase in the heat production in the morning experiment is even greater, the increase ranging from 287 calories on the morning following the first night of the fast to 90 calories following the twenty-eighth night of the fast. These increments, which are given in the last column of the table, indicate admirably the increase in the total heat production due to the difference between lying asleep and lying awake.

Comparing the values for the heat production obtained with the respiration apparatus on the basis of per kilogram of body-weight, we find that a maximum heat production of 1.13 calories was found on the morning following the first night of the fast and also on the last morning of the whole series of experiments, with a minimum heat production of 0.93 on the morning following the twenty-third night. These values also show a general tendency to decrease until about the twentieth day of the fast, remaining approximately constant at a low level for a number of days and rising toward the end of the fast, thus indicating a distinct tendency for the heat production per kilogram of body-weight to be somewhat higher in the last week than it is in the third week of fasting.

When the values for the heat production are considered on the basis of per square meter of body-surface, a maximum value is found of 859 calories on the morning following the first night of the fast, and a minimum value of 668 calories on the morning following the twenty-third night of the fast. There is a distinct tendency for this value to decrease progressively until the eighteenth day, and from that time to show a general tendency toward equalization, but there is no definite indication of the increase during the last week of the fast observed in values found by other methods of computation. It is interesting to note that the values for the heat production per square meter of body-surface, as computed from the data obtained with the respiration apparatus, are the only values which do not indicate the tendency to an increased metabolism in the last week of fasting.

All of these computations of the heat production by the indirect method therefore substantiate almost completely the inferences already drawn as to the effect of a prolonged fast upon the respiratory exchange, *i. e.*, there is here a progressive falling off in the total amount of heat produced during the first 21 days of fasting, with a tendency thereafter for the heat to remain constant or to increase somewhat.

BALANCE OF INCOME AND OUTGO.

While it was impracticable to have this fasting subject remain in the respiration calorimeter for the entire time, as in the fasting experiments at Wesleyan University, and thus secure ideal conditions for studying the total metabolism and energy transformation during the fast, yet, recognizing the great value of a knowledge of the entire 24-hour energy transformation, we attempted to secure as frequent respiration experiments as possible to supplement the data obtained inside the respiration calorimeter during the night. This supplied a logical basis for a subsequent computation of the total energy transformation.

The intake of this subject consisted of pure distilled water and oxygen from the air. The output consisted of the water of respiration and perspiration, the carbon-dioxide excretion from the lungs, and the water and solids of the urine. Theoretically, one should not overlook the small quantities of solid matter in the perspiration, these being removed by the baths in distilled water.

The oxygen in the intake appeared in the output combined with either carbon or hydrogen, since the oxygen entered into the combustion of body material. In this combustion heat was liberated, which left the body through various paths—by simple radiation and conduction; as the sensible heat of excreta, *i. e.*, the heat of the urine; and as heat required to vaporize water and to warm the inspired air to the body-temperature.

For a complete understanding of the various components of the output, particularly when considered upon the basis of the total energy transformation in 24 hours, it is necessary to know the elementary composition of the excreta. This requires a knowledge of the total amount of water given off, either as liquid water or as water-vapor, the carbon, hydrogen, and oxygen in the solid matter of urine, and the nitrogen in the urine and the perspiration. Certain of these factors were directly determined. Thus we have direct determinations of the nitrogen and carbon in the urine and of the nitrogen of perspiration. The others can only be computed indirectly, for while we have accurate evidence regarding the carbon-dioxide excretion throughout the night period, when the subject was inside the bed calorimeter, we have no complete evidence of the carbon-dioxide excretion for the daytime, when he was outside of the calorimeter. Our first problem, then, is to estimate the probable katabolism of the subject throughout each 24 hours.

TOTAL KATABOLISM PER 24 HOURS.

Knowing, as we do, the influence upon the katabolism of the slightest muscular activity, it is obvious that the carbon-dioxide output during the night represents a minimum amount for this subject and that during

the day this will be materially increased. Fortunately the experiments made with the respiration apparatus supply evidence which enables us to compute this excretion of carbon dioxide with reasonable accuracy. Thus we have respiration experiments in the morning, with the subject lying upon a couch, which give values higher than those obtained during the night in the respiration chamber. We have also, in the latter part of the fast at least, a series of observations with the subject lying on a couch just prior to his entering the calorimeter, which give values still higher than those obtained with the same apparatus in the morning. On certain days we have values obtained while the subject was sitting quietly in a chair or sitting writing. The increase in katabolism due to these changes in body position and activity has already been noted in considering the respiratory exchange.

Roughly speaking, the subject was inside the respiration calorimeter for approximately 11 or 12 hours each night; during 10 hours of this time the katabolism was directly determined; from the measured value we may estimate the probable katabolism during the entire sojourn of 11 or 12 hours in the respiration calorimeter. The katabolism was determined on the respiration apparatus for a period of approximately 2 hours in the morning and an hour at night, making a sum total of time during which the respiratory exchange was actually measured, at least in the last part of the fast, of from 14 to 15 hours. The remainder of the time, *i. e.*, some 9 or 10 hours, the subject was variously occupied in the laboratory, for the most part sitting, either writing, or talking with the various men examining him. A number of respiration experiments were made which were specially designed to secure information regarding the probable katabolism during such periods of minor physical activity.

DAILY ACTIVITY.

From the notes made by the observers on the various experimental record sheets and by the watchers at other times, it was possible to compute very carefully the number of minutes spent by the subject on each day of the fast in different occupations. His daily routine consisted of practically five degrees of activity—lying, sitting resting, sitting active, standing, and walking. Since there was a distinct diurnal variation in the katabolism, lying in the evening, which was based upon the evening respiration experiments, was accorded a different value from that given to lying in the morning.

To show the subdivision of the day into these various activities, the number of hours and minutes occupied in the various positions is recorded in table 59. The first column shows the period when the subject was lying in the morning, this including the time from the end of the calorimeter experiment to the time that he was weighed. The lying in the evening includes the entire time from the moment he lay down on the

couch up to the beginning of the first period of the calorimeter experiment, although a part of the time was spent lying inside the calorimeter chamber, *i. e.*, the preliminary period of the calorimeter experiment. The third column gives the time spent by the subject lying in the apparatus during the calorimeter experimental period, which usually ended about 8 a. m.

TABLE 59.—*Summary of daily activities in experiment with L. (8 a. m. to 8 a. m.).*[1]

Date.	Day of fast.	Lying.				Sitting.		Standing.	Walking.
		Morning.		Evening.		Night.		Active.		Resting.			
1912.		*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*min.*	*min.*
Apr. 14–15....	1st...	1	49	0	50	10	30	9	2	1	30	4	15
15–16....	2d...	1	43	1	29	10	19	8	40	1	30	4	15
16–17....	3d...	1	45	1	2	10	38	7	31	2	25	24	15
17–18....	4th..	2	0	0	39	11	2	7	8	2	52	4	15
18–19....	5th..	1	45	1	13	10	3	8	45	1	30	29	15
19–20....	6th..	1	40	1	12	10	30	8	49	1	30	4	15
20–21....	7th..	1	35	0	59	10	37	8	19	2	1	14	15
21–22....	8th..	1	25	1	27	10	13	8	31	2	0	4	20
22–23....	9th..	1	50	1	30	10	10	8	41	1	30	4	15
23–24....	10th..	1	24	0	56	10	48	7	57	2	16	24	15
24–25....	11th..	1	46	0	59	10	42	7	23	2	51	4	15
25–26....	12th..	1	40	1	15	10	20	7	56	2	0	29	20
26–27....	13th..	1	36	2	21	10	7	6	8	3	24	4	20
27–28....	14th..	1	40	3	27	9	47	6	4	2	13	14	35
28–29....	15th..	1	32	2	27	10	33	7	29	1	30	14	15
29–30....	16th..	1	25	2	37	10	14	7	55	1	30	4	15
Apr. 30–May 1.	17th..	1	30	2	30	10	31	7	20	1	30	24	15
May 1– 2....	18th..	1	25	2	21	10	45	7	40	1	30	4	15
2– 3....	19th..	1	27	3	0	10	9	6	40	2	0	29	15
3– 4....	20th..	1	39	2	35	10	25	7	32	1	30	4	15
4– 5....	21st...	1	25	1	6	10	29	9	1	1	30	14	15
5– 6....	22d...	1	28	3	35	9	46	7	22	1	30	4	15
6– 7....	23d...	1	45	2	44	10	25	7	17	1	30	4	15
7– 8....	24th..	1	28	2	38	10	26	7	19	1	30	24	15
8– 9....	25th..	1	30	3	54	9	19	7	3	1	30	29	15
9–10....	26th..	1	40	3	9	9	52	7	30	1	30	4	15
10–11....	27th..	1	30	3	52	9	13	7	36	1	30	4	15
11–12....	28th..	1	16	2	53	10	5	7	47	1	30	14	15
12–13....	29th..	1	55	2	45	10	30	7	31	1	0	4	15
13–14....	30th..	2	0	3	11	9	59	7	26	1	0	4	20
14–15....	31st...	2	14	2	23	10	22	6	57	1	0	49	15

[1]To the activity here given should be added the work of dressing and undressing, bathing and raising and lowering the body on the stairs. For explanation of estimates in certain portions of this summary, see text.

For a large part of the day the subject was busy writing, handling his papers, gesticulating, and arguing, and hence was on a distinctly higher metabolic level than when he sat quietly with complete muscular repose. The sitting periods have therefore been classified under two heads, designated respectively as "sitting resting" and "sitting active." All of the time not otherwise accounted for in the table is classified as "sitting active," including the periods of the writing

respiration experiments and the psychological and other tests, except for the time occupied by Professor Anderson's physical measurements and Dr. Langfeld's dynamometer tests.

The designation "standing" includes the time spent in the dynamometer tests, in being photographed, in the physical measurements, and in bathing. The dynamometer tests required 4 minutes, the photographing 20 minutes, the physical measurements 25 minutes, and the standing for the bath 10 minutes. Practically 15 minutes each day were spent in walking, although on a few days somewhat more time than this was so occupied. Besides the regular daily routine, there were varying amounts of work done by lifting the body in going up and down the balcony stairs and occasionally to other portions of the building. This work has also been taken account of in the computations.

TOTAL CARBON-DIOXIDE PRODUCTION AND OXYGEN CONSUMPTION PER 24 HOURS.

The results of the computation of the total amount of carbon dioxide probably produced by the subject and the oxygen consumed in 24 hours are given in table 60. Using the values given in table 59 for the amount of time spent in the various activities, and the carbon dioxide and oxygen measured in the morning respiration experiments, we may easily compute the carbon-dioxide output and oxygen intake of the subject while lying in the morning. The values given in table 60 for lying in the evening were obtained by using the data secured in the evening respiration experiments. These were available only after the eleventh day of the fast, but since an increment in the metabolism was regularly noted in the evening experiments over that of the morning experiments, a correction of 5 per cent has been applied to the morning values to secure the values for lying in the evening when actual measurements were not available.

For the calorimeter experiments we have, of course, the direct measurements of the carbon-dioxide output and oxygen intake without further computation. Moreover, for computing the values for "sitting active" and "sitting resting," we have on various days direct measurements of both the carbon dioxide produced and the oxygen consumed during such periods. These absolute values tended to decrease regularly as the fast continued and with such a degree of regularity that we may very properly interpolate and thus obtain a highly probable figure for each day of the fast to supplement the results of actual determinations.

For a relatively short time each day the subject was standing. Information regarding the increase in the metabolism over lying due to standing is as yet very incomplete. During the winter of 1913–1914 Dr. Hans Murschhauser, Research Associate of the Carnegie Institution of Washington, conducted a series of experiments at the Nutrition

TABLE 60.—*Carbon-dioxide production and oxygen consumption in liters per 24 hours in experiment with L. (8 a. m. to 8 a. m.)*

Date.	Day of fast.	Carbon dioxide.									
		Lying.			Sitting.		Standing.	Walking.	Dressing and undressing.	Going up and down stairs.	Total.
		Morning.	Evening.	Night.	Active.	Resting.					
1912.											
Apr. 14–15.....	1st.	19.84	9.55	104.05	125.74	16.65	0.80	5.46	3.33	0.89	286.3
15–16.....	2d..	19.06	17.27	98.55	120.64	16.65	.82	5.55	1.67	.85	281.1
16–17.....	3d..	18.90	11.72	96.30	101.48	25.96	4.75	5.40	6.44	.82	271.8
17–18.....	4th.	20.28	6.90	99.15	90.74	29.93	.74	5.07	1.57	.80	255.2
18–19.....	5th.	16.70	12.19	86.53	105.00	15.21	5.08	4.77	6.08	.79	252.4
19–20.....	6th.	15.80	11.95	82.99	104.74	14.76	.70	4.74	1.48	.77	237.9
20–21.....	7th.	14.06	9.15	86.11	94.31	19.36	2.28	4.44	5.76	.76	*237.9
21–22.....	8th.	13.01	14.01	83.86	96.58	18.72	.67	6.12	1.41	.76	235.1
22–23.....	9th.	16.61	14.31	81.55	98.47	13.68	.66	4.53	2.74	.77	233.3
23–24.....	10th.	12.01	8.40	84.19	85.38	20.13	3.77	4.29	3.99	.75	222.9
24–25.....	11th.	15.16	8.85	81.95	79.30	24.62	.63	4.29	2.59	.75	218.1
25–26.....	12th.	14.00	11.03	79.92	83.30	17.16	4.47	5.60	3.86	1.48	220.8
26–27.....	13th.	13.44	19.60	76.16	64.40	28.97	.62	5.60	2.56	.74	212.1
27–28.....	14th.	14.00	28.34	70.55	63.70	18.75	2.16	9.80	3.81	1.82	*214.5
28–29.....	15th.	12.33	19.70	74.29	75.43	12.06	2.06	4.02	2.41	1.90	204.2
29–30.....	16th.	11.22	21.51	72.23	77.90	11.88	.58	3.96	1.19	1.07	201.5
Apr. 30–May 1.	17th.	11.97	20.10	72.45	69.52	11.97	3.50	3.99	4.78	.70	199.0
May 1– 2.....	18th.	11.05	18.33	74.03	70.38	11.70	.57	3.90	1.17	1.38	192.5
2– 3.....	19th.	10.70	23.04	68.65	61.20	14.76	3.92	3.69	4.42	.68	191.1
3– 4.....	20th.	12.57	19.53	71.57	69.16	11.43	.56	3.81	1.15	1.36	191.1
4– 5.....	21st.	10.54	8.58	70.62	82.77	11.16	1.90	3.72	4.46	1.39	*196.5
5– 6.....	22d..	11.09	26.88	65.29	67.63	11.34	.56	3.78	1.14	1.35	189.1
6– 7.....	23d..	13.02	20.50	70.39	66.86	11.16	.54	3.72	2.23	.68	189.1
7– 8.....	24th.	10.65	19.91	68.52	69.80	10.89	3.19	3.63	3.27	1.01	190.9
8– 9.....	25th.	10.98	29.25	62.08	67.26	10.98	3.89	3.66	4.40	.67	193.2
9–10.....	26th.	12.50	23.44	65.93	71.10	11.25	.55	3.75	1.13	.66	190.3
10–11.....	27th.	11.07	29.70	61.65	72.05	11.07	.54	3.69	2.21	1.32	193.3
11–12.....	28th.	9.80	21.80	69.72	73.32	11.61	1.99	3.87	3.48	.98	*198.0
12–13.....	29th.	14.84	20.30	70.82	70.81	7.44	.54	3.72	2.23	1.31	192.0
13–14.....	30th.	15.12	23.49	66.05	69.58	7.44	.54	4.96	1.12	1.29	189.6
14–15.....	31st.	16.48	18.16	71.33	65.05	7.14	6.42	3.57	6.42	.95	195.5

*The carbon-dioxide production assumed for the work of bathing was on April 20–21, 1.63 liters; April 27–28, 1.54 liters; May 4–5, 1.36 liters; May 11–12, 1.42 liters.

Laboratory with a professional athlete, in which the subject walked on a treadmill of special construction. Basal figures for these studies were supplied by the results of a large number of determinations (made by Dr. Cathcart)[1] of the metabolism of this man while in a lying position.

A control experiment which was made within a few months by Mr. L. E. Emmes, of the Laboratory staff, shows a close agreement with the earlier observations of Cathcart. Dr. Murschhauser's observations other than walking have dealt entirely with determinations of the metabolism while the subject was standing in various positions, such as

[1]Benedict and Cathcart, Carnegie Inst. Wash. Pub. 187, 1913, p. 77.

TABLE 60.—*Carbon-dioxide production and oxygen consumption in liters per 24 hours in experiment with L. (8 a. m. to 8 a. m.)*—Continued.

Date.	Day of fast.	Oxygen.									
		Lying.			Sitting.		Standing.	Walking.	Dressing and undressing.	Going up and down stairs.	Total.
		Morning.	Evening.	Night.	Active.	Resting.					
1912.											
Apr. 14–15.....	1st.	24.31	11.70	133.33	169.10	22.86	0.98	6.69	4.57	1.11	374.7
15–16.....	2d..	24.41	22.16	130.59	162.24	22.86	1.04	7.11	2.29	1.10	373.8
16–17.....	3d..	23.84	14.76	131.38	135.30	35.38	6.00	6.81	8.78	1.09	363.3
17–18.....	4th.	27.12	9.24	133.73	127.97	40.76	1.00	6.78	2.14	1.07	349.8
18–19.....	5th.	22.26	16.28	115.68	147.53	20.70	6.76	6.36	8.28	1.05	344.9
19–20.....	6th.	20.50	15.48	122.04	142.30	20.16	.90	6.15	2.02	1.05	330.6
20–21.....	7th.	19.00	12.39	121.40	131.74	26.38	3.08	6.00	7.84	1.04	*331.1
21–22.....	8th.	17.34	18.62	114.85	134.90	25.44	.90	8.16	1.91	1.03	323.2
22–23.....	9th.	22.33	19.17	108.45	137.54	18.54	.89	6.09	3.71	1.03	317.8
23–24.....	10th.	15.96	11.20	116.52	118.77	27.20	5.02	5.70	5.40	1.01	306.8
24–25.....	11th.	19.82	11.56	112.88	109.42	33.17	.82	5.61	3.49	1.01	297.8
25–26.....	12th.	18.70	14.70	108.76	117.10	23.28	5.97	7.48	5.24	2.00	303.2
26–27.....	13th.	17.95	27.21	102.47	90.53	39.58	.82	7.48	3.49	1.00	290.5
27–28.....	14th.	19.20	40.08	98.06	89.54	26.60	2.95	13.44	5.40	2.53	*299.9
28–29.....	15th.	16.65	27.93	103.70	106.86	16.92	2.79	5.43	3.38	2.64	286.3
29–30.....	16th.	15.22	29.67	101.92	110.68	16.92	.79	5.37	1.69	1.49	283.8
Apr. 30–May 1.	17th.	16.38	28.50	101.14	98.56	16.92	4.80	5.46	6.76	.97	279.5
May 1– 2.....	18th.	15.47	26.51	102.78	98.90	16.92	.80	5.46	1.69	1.94	270.5
2– 3.....	19th.	15.14	34.02	96.22	86.00	21.60	5.54	5.22	6.48	.97	271.2
3– 4.....	20th.	17.52	28.21	100.32	97.18	16.20	.78	5.31	1.62	1.92	269.1
4– 5.....	21st.	14.71	12.01	97.04	116.32	16.20	2.66	5.19	6.48	1.90	*274.4
5– 6.....	22d..	15.31	39.13	90.30	95.03	16.20	.76	5.22	1.62	1.90	265.5
6– 7.....	23d..	17.85	28.86	97.73	93.96	15.84	.75	5.10	3.17	.94	264.2
7– 8.....	24th.	14.52	27.65	99.18	97.46	15.48	4.37	4.95	4.65	1.40	269.7
8– 9.....	25th.	15.03	41.42	85.69	93.91	15.48	5.34	5.01	6.20	.93	269.0
9–10.....	26th.	16.60	33.26	94.37	99.90	15.48	.73	4.98	1.55	.92	267.8
10–11.....	27th.	15.12	41.76	85.63	101.23	15.48	.74	5.04	3.10	1.84	269.9
11–12.....	28th.	13.07	31.31	98.11	103.21	15.48	2.65	5.16	4.65	1.36	*276.9
12–13.....	29th.	19.67	29.37	98.32	99.67	10.32	.73	4.98	3.10	1.82	268.0
13–14.....	30th.	20.76	34.00	91.75	98.57	10.32	.75	6.84	1.55	1.79	266.3
14–15.....	31st.	22.38	26.17	99.41	92.16	10.32	8.97	4.98	9.30	1.34	275.0

*The oxygen consumption assumed for the work of bathing was on April 20–21, 2.20 liters; April 27–28, 2.11 liters; May 4–5, 1.90 liters; May 11–12, 1.89 liters.

"attention," "relaxed," and similar positions. Using as a basis Cathcart's and Emmes' figures for lying and Dr. Murschhauser's values for standing, we find an increase over lying of about 10 per cent. Consequently this 10 per cent increment has been used to compute the value for standing for our fasting subject.

For the values for walking we have relied implicitly upon the extensive series of observations made by Dr. Murschhauser with the professional athlete. This subject showed an increment of 190 per cent in the metabolism while walking at a slow pace—60.6 meters per minute—over that while lying. Recognizing the fact that Dr.

Murschhauser's subject was a trained athlete and represented the highest degree of muscular vigor and that our subject was a non-athlete, flabby, and, as the fast progressed, still more emaciated and less inclined to physical exercise, we have employed but 100 per cent for the computation of the value for L., since there was here the possibility of a very considerable error. Fortunately, as will be seen by reference to table 60, the total carbon-dioxide production and oxygen consumption while the subject was walking was hardly 2 per cent of the total value for the day; we may therefore consider any error present as entirely negligible.

For the numerous physical tests and the photographing, the subject had to dress and undress at least once or twice each day and on some days several times. The metabolism involved in dressing and undressing was studied in a large number of experiments in the respiration calorimeter at Wesleyan University,[1] and it was found that the resting metabolism was increased 30 per cent during one hour. Accordingly the values obtained while the subject was sitting resting were increased by 30 per cent of the resting metabolism for one hour to allow for this muscular work of dressing and undressing. Here, again, the absolute values involved are extremely small when compared with the total for the day. On 4 days an additional allowance was made for the work of bathing, this being considered as equivalent to the metabolism for 10 minutes of standing. The value for this on the seventh day of the fast was 1.63 liters of carbon dioxide and 2.20 liters of oxygen; on the fourteenth day it was 1.54 liters of carbon dioxide and 2.11 liters of oxygen; on the twenty-first day it was 1.36 liters of carbon dioxide and 1.90 liters of oxygen; and on the twenty-eighth day it was 1.42 liters of carbon dioxide and 1.89 liters of oxygen.

A further computation was made of the metabolism involved in the work of going up and down stairs. For lack of better evidence, it was estimated that the amount of work performed in going down stairs was equal to half of that going up. The number of kilogrammeters were computed by multiplying the weight of the man by the height through which he lifted his body, increasing this by one-half when the work of going down stairs was included. The number of calories were then obtained by dividing the number of kilogrammeters by the factor 426.6. Finally, by using the calorific equivalent for the average respiratory quotient for the day, computed from the results of the experiments with the calorimeter and the respiration apparatus, we were able to calculate the amount of carbon dioxide excreted and oxygen consumed in the muscular work of lifting the body. The total probable carbon-dioxide production and oxygen consumption for the 24 hours is therefore the sum of the values computed for the varying degrees of activity; these totals are given in the last column of table 60.

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. 126, 1910, p. 247.

In estimating the probable accuracy of the figures, it is evident that the greatest error is likely to be found in the values for the metabolism with the subject sitting active, since this is a not inconsiderable part of the metabolic activity for the day. An increment of approximately 25 per cent was actually measured during the writing experiments and it has been assumed that when the subject was talking, gesticulating, handling his papers, writing, and not otherwise at complete rest, he was on a metabolic plane comparable to that during the actual period of measurement while he was writing. The values on certain days are undoubtedly a little high and on others a little low, but it is highly improbable that there is an appreciable percentage error when the total 24-hour amounts are considered. The results of these computations for the carbon-dioxide production and oxygen consumption per 24 hours are therefore probably within 3 per cent of the values which would have been obtained had it been possible to make complete and continuous determinations of the respiratory exchange.

The total 24-hour quantity of carbon dioxide produced steadily decreased as the fast progressed, with slightly higher values in the last week. The maximum, 286.3 liters, was found on the first day and the minimum, 189.1 liters, on the twenty-second and twenty-third days. The oxygen consumption followed essentially a parallel course, with a maximum of 374.7 liters on the first day and a minimum of 264.2 liters on the twenty-third day.

CHARACTER OF THE KATABOLISM.

In the discussion of the metabolism of the fasting subject in previous sections of this book, emphasis has been laid upon the minimum amounts or comparable values obtained under like external conditions, in an attempt to study exclusively the influence of the internal processes upon the metabolism, particularly the effect of the prolonged fasting. Hence we find emphasis laid upon the daily alteration in rhythm and the influence of inanition as the fast progressed.

Since Rubner's law of the isodynamic value of the nutrients makes it of relatively little importance as to whether the diet of a normal individual contains 25 or 40 per cent of its total energy in carbohydrates, interest in normal katabolism is centered chiefly upon the total heat-production. On the other hand, it is clear that with a subject living upon body material, any evidence regarding the character of the composition of the katabolized material and the source of energy, particularly in regard to the effect of prolonged fasting upon them, will also have much more than ordinary interest.

We have here a subject living substantially the same daily routine for 31 days of fasting and the 3 days following with food. In the days prior to the fast the subject was distinctly more active. Utilizing the results of the numerous respiration experiments, the measurements

of the metabolism made during the long sojourn of the subject in the respiration calorimeter at night, the daily records of the occupations of the subject during the fast, and standard figures regarding the effect upon the katabolism of variations in activity, we are able to make for practically every hour of the day a reasonably satisfactory estimate of the probable activity and thus obtain the total katabolism.

When complete 24-hour determinations of the various factors entering into the computation of the character of the katabolism can be obtained, namely, the direct measurement of the total carbon-dioxide output, oxygen intake, and elementary composition of the solid matter of urine, the most exact method for computing the character of the katabolism and the kinds and the amounts of material burned is that outlined in the previous publication on inanition, in which use was made of simultaneous equations.[1] When, as is the case with this fasting subject, an element of uncertainty enters into the fundamental figures which would be used in such computations and it is necessary to make our estimates of the total carbon-dioxide output and oxygen intake from the results of fragmentary, periodic determinations, it does not seem justifiable, or indeed logical, to employ the extremely exact mathematical computation used in the earlier publication. It is true that the protein katabolism may be as readily obtained for this experiment as for the experiments previously reported, since we have data as to the total nitrogen excretion, but for the apportionment of the katabolism between fat and carbohydrate a simpler method is probably more justifiable. We have thus first computed the protein katabolism, and then apportioned the katabolism of carbohydrate and fat by a method to be subsequently described.

PROTEIN KATABOLISM.

In accordance with the current conception of the relationship between the nitrogen in the urine and protein katabolism, the total amount of protein katabolized may be computed from the total amount of nitrogen in the urine by using the percentage of nitrogen in the tissue broken down. In ordinary metabolism experiments, when the food ingested is of varying composition and contains proteins of various kinds, it is commonly assumed that the nitrogen in the tissue broken down is represented by the factor 6.25, so that the amount of nitrogen in the urine may be multiplied by this factor to obtain the amount of protein in the tissue broken down. In a fasting experiment, however, only body-material is katabolized and the percentage of nitrogen in dry, fat-free, and ash-free flesh has been shown to be 16.62; hence the factor 6.0 should be used instead of 6.25 for computing the protein in the flesh katabolized from the amount of nitrogen in the urine. Accordingly this factor was used for our computations of the protein katabolism in this experiment.

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, pp. 36 and 452.

In a previous section of this publication (see table 27, p. 251), it has been shown that the nitrogen in the urine gradually decreased as the fast progressed, but the nitrogen excretion per kilogram of body-weight is also of interest in this connection as showing whether or not the decrease was proportional to the loss in weight. From the values given in table 27 it will be seen that after the first 4 days of the fast, during which there was a marked rise in the nitrogen excretion, the values per kilogram of body-weight had a tendency to fall as the fast progressed, the highest value (0.207 gram) being found on the fourth day of fasting and the lowest (0.146 gram) on the twenty-third and thirty-first days of the fast. It is thus unquestionable that there was a distinct tendency in the latter part of the fast for the nitrogen excretion per kilogram of body-weight to be lower than in the first part of the fast. The values for the total nitrogen excreted and the computed amounts of protein katabolized are given in columns A and P, table 61. The protein katabolized ranged from a maximum of 71.2 grams on the fourth day of the fast to a minimum of 41.6 grams on the last day, the course of the protein curve naturally following that of the nitrogen excretion. Finally, on the assumption that flesh contains 20 per cent protein and 80 per cent water, the flesh equivalent of the protein katabolized has been computed by multiplying the protein by 5, the results being given in column Q of table 61. These values obviously follow those for the nitrogen and the protein, the maximum value being 356 grams on the fourth day of fasting and the minimum 208 grams on the last day of the fast.

APPORTIONMENT OF NON-PROTEIN KATABOLISM BETWEEN CARBOHYDRATE AND FAT.

The method used in this publication for computing the katabolism of fat and carbohydrate for our fasting subject was, in brief, as follows:

The amounts of carbon dioxide produced and oxygen consumed in the combustion of carbohydrate and fat were first obtained by deducting the computed amounts for the combustion of protein from the total amounts of carbon dioxide produced and oxygen consumed. From these values the non-protein respiratory quotient for each day of the fast was readily calculated. Using these non-protein respiratory quotients, we next found the total heat given off in the combustion of the carbohydrate and fat, the apportionment of the heat output between them being made subsequently by the use of certain factors. From the heat output due to the combustion of the carbohydrate and the fat, the amounts of these two body materials katabolized were finally calculated by means of their heats of combustion.

Carbon Dioxide Produced and Oxygen Consumed in the Katabolism of Carbohydrate and Fat.

Since we know the amount of nitrogen excreted in the urine, the carbon dioxide produced and the oxygen consumed in the katabolism of protein may be computed by using factors established by Zuntz and his co-workers. Thus, for every gram of nitrogen in the urine, Zuntz has found that 4.75 liters of carbon dioxide are produced and 5.91 liters of oxygen are consumed. The total nitrogen excretion for each day of the fast is given in column A of table 61, and the carbon dioxide produced and the oxygen consumed in the combustion of protein are given in columns C and F respectively. Deducting these values from

Table 61.—*Body materials katabolized and total heat production (computed) per 24 hours in experiment with L.*

Date.	Day of fast.	Nitrogen in urine.	Carbon dioxide.			Oxygen.			Non-protein respiratory quotient (D÷G).
			Total.[1]	From protein burned (A×4.75).	From fat and carbohydrate (B−C).	Total.[1]	For combustion of protein (A×5.91).	For combustion of fat and carbohydrate (E−F).	
		A	B	C	D	E	F	G	H
1912.		*gm.*	*liters.*	*liters.*	*liters.*	*liters.*	*liters.*	*liters.*	
Apr. 14–15....	1st.	7.10	286.3	33.7	252.6	374.7	42.0	332.7	0.76
15–16....	2d..	8.40	281.1	39.9	241.2	373.8	49.6	324.2	.74
16–17....	3d..	11.34	271.8	53.9	217.9	363.3	67.0	296.3	.74
17–18....	4th.	11.87	255.2	56.4	198.8	349.8	70.2	279.6	.71
18–19....	5th.	10.41	252.4	49.4	203.0	344.9	61.5	283.4	.72
19–20....	6th.	10.18	237.9	48.4	189.5	330.6	60.2	270.4	.70
20–21....	7th.	9.79	237.9	46.5	191.4	331.1	57.9	273.2	.70
21–22....	8th.	10.27	235.1	48.8	186.3	323.2	60.7	262.5	.71
22–23....	9th.	10.74	233.3	51.0	182.3	317.8	63.5	254.3	.72
23–24....	10th.	10.05	222.9	47.7	175.2	306.8	59.4	247.4	.71
24–25....	11th.	10.25	218.1	48.7	169.4	297.8	60.6	237.2	.71
25–26....	12th.	10.13	220.8	48.1	172.7	303.2	59.9	243.3	.71
26–27....	13th.	10.35	212.1	49.2	162.9	290.5	61.2	229.3	.71
27–28....	14th.	10.43	214.5	49.5	165.0	299.9	61.6	238.3	.69
28–29....	15th.	8.46	204.2	40.2	164.0	286.3	50.0	236.3	.69
29–30....	16th.	9.58	201.5	45.5	156.0	283.8	56.6	227.2	.69
Apr. 30–May 1.	17th.	8.81	199.0	41.8	157.2	279.5	52.1	227.4	.69
May 1– 2....	18th.	8.27	192.5	39.3	153.2	270.5	48.9	221.6	.69
2– 3....	19th.	8.37	191.1	39.8	151.3	271.2	49.5	221.7	.68
3– 4....	20th.	7.69	191.1	36.5	154.6	269.1	45.5	223.6	.69
4– 5....	21st.	7.93	196.5	37.7	158.8	274.4	46.9	227.5	.70
5– 6....	22d..	7.75	189.1	36.8	152.3	265.5	45.8	219.7	.69
6– 7....	23d..	7.31	189.1	34.7	154.4	264.2	43.2	221.0	.70
7– 8....	24th.	8.15	190.9	38.7	152.2	269.7	48.2	221.5	.69
8– 9....	25th.	7.81	193.2	37.1	156.1	269.0	46.2	222.8	.70
9–10....	26th.	7.88	190.3	37.4	152.9	267.8	46.6	221.2	.69
10–11....	27th.	8.07	193.3	38.3	155.0	269.9	47.7	222.2	.70
11–12....	28th.	7.62	198.0	36.2	161.8	276.9	45.0	231.9	.70
12–13....	29th.	7.54	192.0	35.8	156.2	268.0	44.6	223.4	.70
13–14....	30th.	7.83	189.6	37.2	152.4	266.3	46.3	220.0	.69
14–15....	31st.	6.94	195.5	33.0	162.5	275.0	41.0	234.0	.69

[1]See table 60.

the computed 24-hour values for the total carbon dioxide given off and oxygen consumed, we obtain the carbon dioxide and oxygen for the combined combustion of the fat and carbohydrate, these amounts being given in columns D and G of the table. The ratio of these two values gives the so-called non-protein respiratory quotient, which is recorded in column H.

Significance of the Non-Protein Respiratory Quotients.

Since the non-protein respiratory quotient has a special significance in this connection, a discussion of the values for the quotients given in table 61 may be made here before going further with the computation of the amounts of body materials katabolized.

TABLE 61.—*Body materials katabolized and total heat production (computed) per 24 hours in experiment with L.*—Continued.

Date.	Day of fast.	Heat computed.					Body materials katabolized.			Flesh equivalent of protein (P×5).
		From fat and carbohydrate.[1]	From carbohydrate.[1]	From fat.[1]	From protein (A×26.51).	Total (J+K+L).	Carbohydrate (J÷4.23).	Fat (K÷9.54).	Protein (A×6.0).	
		I	J	K	L	M	N	O	P	Q
1912.		*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*gm.*	*gm.*	*gm.*	*gm.*
Apr. 14–15.....	1st.	1581	291	1290	188	1769	68.8	135	42.6	213
15–16.....	2d..	1533	178	1355	223	1756	42.1	142	50.4	252
16–17.....	3d..	1401	163	1238	301	1702	38.5	130	68.0	340
17–18.....	4th.	1311	18	1293	315	1626	4.3	136	71.2	356
18–19.....	5th.	1333	64	1269	276	1609	15.1	133	62.5	312
19–20.....	6th.	1267	...	1267	270	1537	....	133	61.1	306
20–21.....	7th.	1280	...	1280	260	1540	....	134	58.7	294
21–22.....	8th.	1231	17	1214	272	1503	4.0	127	61.6	308
22–23.....	9th.	1196	57	1139	285	1481	13.5	119	64.4	322
23–24.....	10th.	1160	16	1144	266	1426	3.8	120	60.3	302
24–25.....	11th.	1113	16	1097	272	1385	3.8	115	61.5	308
25–26.....	12th.	1141	16	1125	269	1410	3.8	118	60.8	304
26–27.....	13th.	1075	15	1060	274	1349	3.5	111	62.1	311
27–28.....	14th.	1117	...	1117	277	1394	....	117	62.6	313
28–29.....	15th.	1107	...	1107	224	1331	....	116	50.8	254
29–30.....	16th.	1065	...	1065	254	1319	....	112	57.5	287
Apr. 30–May 1.	17th.	1066	...	1066	234	1300	....	112	52.9	265
May 1– 2.....	18th.	1038	...	1038	219	1257	....	109	49.6	248
2– 3.....	19th.	1039	...	1039	222	1261	....	109	50.2	251
3– 4.....	20th.	1048	...	1048	204	1252	....	110	46.1	231
4– 5.....	21st.	1066	...	1066	210	1276	....	112	47.6	238
5– 6.....	22d..	1030	...	1030	205	1235	....	108	46.5	233
6– 7.....	23d..	1036	...	1036	194	1230	....	109	43.9	220
7– 8.....	24th.	1038	...	1038	216	1254	....	109	48.9	245
8– 9.....	25th.	1044	...	1044	207	1251	....	109	46.9	235
9–10.....	26th.	1037	...	1037	209	1246	....	109	47.3	237
10–11.....	27th.	1041	...	1041	214	1255	....	109	48.4	242
11–12.....	28th.	1087	...	1087	202	1289	....	114	45.7	229
12–13.....	29th.	1047	...	1047	200	1247	....	110	45.2	226
13–14.....	30th.	1031	...	1031	208	1239	....	108	47.0	235
14–15.....	31st.	1097	...	1097	184	1281	....	115	41.6	208

[1]For the factors used in this computation see Williams, Riche and Lusk, Journ. Biol. Chem., 1912, **12**, p. 357.

We found in this experiment none of the extraordinarily low values reported by other observers with fasting man, the lowest quotient obtained with our subject being 0.68, which was found for but one day. When the difficulties in securing accurate determinations of the respiratory quotients are considered—all of the errors in the determination of both the oxygen consumption and the carbon-dioxide production affecting the value of the respiratory quotient—it is perhaps surprising that values more abnormal than those shown in column H are not found. It is of course not impossible that abnormal katabolism resulting from the acidosis of this man may in part account for this slightly lowered respiratory quotient.

In fasting there is unquestionably a larger excretion of ammonia in the urine and likewise an excretion of β-oxybutyric acid. Indeed, an attempt has been made by Grafe[1] to correct for the alteration in the values for the respiratory quotient when ammonia is excreted in the urine instead of the ordinary urea. It may be questioned, however, whether data obtainable in fasting experiments are sufficiently accurate and the oxygen measurements are sufficiently exact to warrant such an attempt. Furthermore, since the alteration from urea to ammonia is merely a matter of hydrolysis, the computation may prove to be somewhat problematical. In all probability the protein katabolism is not greatly affected, for while there is a distinct disturbance in the relationship between the ammonia and the total nitrogen, there is not an excessive amount of amino-acids formed, as the rest nitrogen is not unduly large. On the other hand, Magnus-Levy[2] has clearly shown that the formation of acetone bodies due to the partial oxidation of fat results in the absorption of oxygen and production of carbon dioxide, thus influencing slightly the respiratory quotient, but concludes that a production of 40 grams of β-oxybutyric acid alters the respiratory quotient not more than 0.012.

A not inconsiderable proportion of the total energy transformation, as here computed, is based upon experiments made with the respiration apparatus, in which the cutaneous respiration was not considered. The respiratory quotient might thus have been slightly higher had the cutaneous respiration also been determined, Magnus-Levy mentioning 0.015 as the probable correction to be applied to the respiratory quotient determined by nose or mouth appliances.

While the determinations of the respiratory quotient by means of the bed calorimeter and the respiration apparatus check each other and show that the results are within a few units of being accurate, nevertheless when the protein katabolism correction amounts to but a few thousandths and the correction for the formation of acetone bodies also amounts to only a few thousandths, it can be seen that the

[1]Grafe, Zeitschr. f. physiol. Chemie, 1910, **65**, p. 21.
[2]Magnus-Levy, Zeitschr. f. klin. Med., 1905, **56**, p. 83.

degree of accuracy in the determination of the respiratory quotient must be extraordinarily high to admit of an intelligent discussion of these points. Furthermore, it is reasonable to question whether or not one can logically use the determination of the respiratory quotient for analyzing in any way the organic processes which are affected during fasting. It is certain, of course, that the combustion of fat forms the greatest part of the total combustion. On the other hand, there may be a slight formation of carbohydrate on some days which would alter the quotient; there may also be an abnormal excretion of materials in the urine which would likewise alter the respiratory quotient; and there is always a possibility of the production of β-oxybutyric acid. All of these factors, however, affect the quotient but slightly, and therefore no great stress need be laid upon them. In fact, it is doubtful, as was pointed out in the earlier fasting publication, whether the computation of the total glycogen output was sufficiently accurate to justify the assumption that glycogen was actually produced on 2 days of fasting. I believe that the computations of the 24-hour gaseous exchange in the experiment with L. are not sufficiently accurate to throw definite light upon the question as to whether or not glycogen was produced after the first few days of the fast.

The general course of the respiratory quotients found with L. is wholly in accord with those observed with the Middletown subject S. A. B., who remained in the respiration calorimeter the entire period of the experiment, except that the quotients obtained for the latter subject were almost invariably somewhat higher. Thus, the average respiratory quotients for the 7 days of the fasting experiment with S. A. B. were 0.78, 0.75, 0.74, 0.75, 0.74, 0.75, and 0.74, these values being substantially higher than those observed for our subject L. on the fourth to seventh days of his fast. The respiratory quotients for L. given in column H of table 61 are, however, non-protein respiratory quotients, while those here given for S. A. B. are the total respiratory quotients. *i. e.*, they include the protein katabolism. Hence the disparity is not so great, as the respiratory quotient for protein is not far from 0.81. In any event, it is clear that we do not have here sufficient evidence of so great a disturbance in either fat, carbohydrate, or protein katabolism as to lead us to believe that there was a fundamental alteration in the character of the katabolism, other than that accompanying the acidosis during the 31-day fast.

Energy Derived from Katabolism of Carbohydrate and Fat.

Using these values for the non-protein respiratory quotient, the oxygen consumption required for the combustion of the fat and carbohydrate (column G of table 61), and the calorific equivalents of oxygen given in Zuntz and Schumburg's table,[1] we are able to compute the energy

[1]Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.

derived from the carbohydrate and fat katabolized. For instance, on April 14–15, the first day of the fast, the non-protein respiratory quotient was 0.76. The calorific equivalent of oxygen with this respiratory quotient is 4.752 calories per liter; hence the total heat given off from the combustion of the fat and carbohydrate would be equal to the oxygen consumed in the combustion (332.7 liters) multiplied by the calorific equivalent for this non-protein respiratory quotient, *i. e.*, 4.752, the calculation being $332.7 \times 4.752 = 1{,}581$ calories. The values for the total heat resulting from the combustion of the fat and carbohydrate for each day of the fast are given in column 1 of table 61.

The table of Zuntz and Schumburg has been elaborated in a most helpful and ingenious way by Williams, Riche, and Lusk,[1] who have apportioned (in terms of percentage of total energy) the fat-carbohydrate katabolism, using the non-protein respiratory quotient. With a non-protein respiratory quotient of 0.76, these authors compute that 18.4 per cent of the energy is derived from carbohydrate and 81.6 per cent from fat; consequently, on April 14–15 about 18.4 per cent of the 1,581 calories as calculated previously, or 291 calories, are derived from the katabolism of carbohydrate, and the remaining 1,290 calories from fat. Obviously, as the non-protein respiratory quotient falls, the percentage of energy derived from carbohydrate becomes less and less, until, at 0.70 or less, it is assumed that no carbohydrate is burned. In fact, on several days when the non-protein respiratory quotient was 0.69 and on one day 0.68, we have followed Lusk's usage in employing the value for the quotient of 0.70.

Amounts of Carbohydrate and of Fat Katabolized.

Since Williams, Riche, and Lusk were particularly interested in the energy transformation, their apportionment of the non-protein katabolism between fat and carbohydrate was expressed in percentage of energy from carbohydrate and percentage of energy from fat. For our purpose, since we desire the weight of the carbohydrate and fat burned, it is very simple to compute the heat production and then by dividing by the appropriate calorific values for carbohydrate and fat, obtain directly the number of grams of carbohydrate and fat entering into the katabolism.

The heat of combustion of the carbohydrate burned in the body is taken as that of glycogen, 4.23 calories per gram,[2] while the heat of combustion for the fat is taken as that of body fat, 9.54 calories per gram.[3] By dividing the respective amounts of energy by these heats of combustion, the number of grams of glycogen and body fat participating in the katabolism are computed. These are recorded in columns N and O in table 61. While this method of computing the probable

[1]Williams, Riche, and Lusk, Journ. Biol. Chem., 1912, **12**, p. 357.
[2]Emery and Benedict, Am. Journ. Physiol., 1911, **28**, p. 301.
[3]Benedict and Osterberg, Am. Journ. Physiol., 1900, **4**, p. 69.

24-hour amounts of body materials katabolized is by no means comparable with that resulting from exact continuous measurements with the respiration calorimeter, it nevertheless has a value.

Katabolism of carbohydrate.—On the basis of the non-protein respiratory quotients as computed for 24 hours, it is seen that there is a combustion of body carbohydrate or glycogen for the first 5 days and a probable combustion for 6 days later in the fast. The maximum amount of carbohydrate katabolized was 68.8 grams on the first day of fasting and the minimum was practically 4 grams on the 4 days from the tenth to the thirteenth days inclusive. These amounts are somewhat smaller than those found for the average of all of the short fasting experiments at Wesleyan University. In these experiments the average katabolism for the 7 days was 110, 40.3, 21.8, 23.3, 8.2, 21.7, and 18.7 grams, respectively; these values are not dissimilar from those found in the 7-day experiment with S. A. B., in which but 64.9 grams of glycogen were katabolized on the first day. The findings with L. are wholly in line with those observed on S. A. B. and show that there is a material katabolism of body carbohydrate or glycogen continuing throughout the first 7 to 10 days of the fast.

Katabolism of fat.—The katabolism of fat decreased regularly as the fast progressed, the maximum amount of 142 grams being observed on the second day of fasting and the minimum amount of 108 grams on the twenty-second and thirtieth days of fasting respectively.

LOSS OF WATER FROM THE BODY.

The loss of organized tissue has been calculated in the previous section with great care and thus light has been thrown upon the transformations of matter in the body during a prolonged fast. Water does not enter into energy changes and yet the data regarding the loss to the body by the excretion of water are of much interest.

An important observation was made in connection with the report of the 7–day fasting experiment in the earlier book[1] to the effect that there was distinct evidence that a large amount of preformed water, other than that of flesh, was discharged from the body in the first 4 or 5 days of the fast and thereafter the loss of water was approximately proportional to the flesh disintegrated and the fat burned.

Water, in so far as it enters into the katabolism of the fasting man, may be considered as coming from two sources, first, preformed water, and second, the water of oxidation of organic matter. From the determined amounts of carbohydrate, fat, and protein katabolized, it is possible, by means of well-known chemical formulæ, to compute the amount of organic hydrogen oxidized during the fast, but the draft upon the store of preformed water as the fast progressed is of much more significance.

[1]Benedict, Carnegie Inst. Wash. Pub. 77, 1907, p. 467.

Although L. went without food for 31 days, and hence the complicated factor of determining the intake of water in the food was eliminated, nevertheless he drank a definite amount of water each day, and water was lost from the body through various paths. We know that in the urine a certain amount of water was mixed with the solids. This was determined very carefully in the latter part of the fast, so that we had accurate information as to the relationship between the total amount of water and total solids, and were accordingly able to compute the water excreted in the urine during the earlier days of the fast. Water was also lost by vaporization from the lungs and skin. In the method formerly used for obtaining the loss of water from the body it was likewise necessary to determine carefully the amount of water thus vaporized in the 24 hours. In this fasting experiment, while such determinations were made for the period when the subject was inside the respiration calorimeter, we have no direct evidence regarding the probable water vaporized from the lungs and skin during the time that L. was outside of the chamber. Even the respiration experiments, while supplying information regarding the carbon-dioxide output and oxygen intake, give no evidence as to the excretion of water. Accordingly, the total outgo of water must be determined by indirect computation. Fortunately the data regarding the katabolism of L. are so full and exact that we are justified in employing such a method.

LOSS OF PREFORMED WATER.

To determine the actual drafts upon body material in the form of preformed water, the computation proceeds in the following manner, the results being given in table 62. We have first the "insensible perspiration" (column A), which is likewise recorded in table 4 (page 84). From the discussion in the preceding section we have information as to the amounts of carbohydrate, fat, and protein which were katabolized in the body. The carbohydrate was completely oxidized, leaving the body in the form of carbon dioxide and water, and hence was a complete loss. The fat was similarly burned to carbon dioxide and water. On the other hand, only a portion of the protein was actually oxidized and, so to speak, volatilized and lost from the body.

Using standard figures, Loewy[1] has computed that for each 100 grams of combustible anhydrous flesh which is katabolized there are available for oxidation and conversion to carbon dioxide and water 41.50 grams of carbon, 4.40 grams of hydrogen, and 7.69 grams of oxygen. Thus, of the total protein molecule, 53.6 per cent may be burned and 46.4 per cent may be excreted in urine or feces. In computing the total weights of carbohydrate, fat, and protein oxidized and volatilized in the body we must therefore allow for 46.4 per cent of the protein excreted in the urine. The values given in column B of table 62

[1]Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, 4 (1), p. 156.

for the anhydrous material burned therefore represent the total weight of carbohydrate burned (column N of table 61), the total weight of fat burned (column O), and 53.6 per cent of the total weight given in table 61 (column P) for the amount of protein burned.

Since the insensible perspiration represents the actual insensible loss from the body, the amount of preformed water vaporized may be

TABLE 62.—*Preformed water vaporized or excreted from the body and drafts upon the original supply in experiment with L.*

Date.	Day of fast.	Insensible perspiration.	Body material (anhydrous) burned.[1]	Preformed water.							
				Vaporized or excreted.			Water consumed.	Loss of preformed water.			
				Vaporized from body (A−B).	Excreted in urine.	Total (C+D).		Total (E−F).	From fatty tissue.[2]	From flesh (N×6.0×4).	From sources other than fat and flesh G−(H+I).
		A	B	C	D	E	F	G	H	I	J
1912.		gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Apr. 14–15	1st.	1086	227	859	630	1489	720	769	14	170	585
15–16	2d.	1188	211	977	437	1414	750	664	14	202	448
16–17	3d.	1059	205	854	531	1385	750	635	13	272	350
17–18	4th.	779	179	600	674	1274	750	524	14	285	225
18–19	5th.	727	182	545	634	1179	750	429	13	250	166
19–20	6th.	606	166	440	578	1018	750	268	13	244	11
20–21	7th.	603	166	437	496	933	750	183	13	235	− 65
21–22	8th.	569	164	405	557	962	750	212	13	246	− 47
22–23	9th.	578	167	411	575	986	750	236	12	258	− 34
23–24	10th.	672	156	516	535	1051	750	301	12	241	48
24–25	11th.	573	152	421	535	956	900	56	12	246	−202
25–26	12th.	691	154	537	490	1027	900	127	12	243	−128
26–27	13th.	436	148	288	532	820	900	− 80	11	248	−339
27–28	14th.	540	151	389	619	1008	900	108	12	250	−154
28–29	15th.	442	143	299	736	1035	900	135	12	203	− 80
29–30	16th.	578	143	435	861	1296	900	396	11	230	155
Apr. 30–May 1	17th.	509	140	369	821	1190	900	290	11	212	67
May 1– 2	18th.	521	136	385	633	1018	900	118	11	198	− 91
2– 3	19th.	550	136	414	705	1119	900	219	11	201	7
3– 4	20th.	371	135	236	679	915	900	15	11	184	−180
4– 5	21st.	623	138	485	685	1170	900	270	11	190	69
5– 6	22d.	465	133	332	763	1095	900	195	11	186	− 2
6– 7	23d.	504	133	371	537	908	900	8	11	176	−179
7– 8	24th.	480	135	345	728	1073	900	173	11	196	− 34
8– 9	25th.	468	134	334	692	1026	900	126	11	188	− 73
9–10	26th.	473	134	339	706	1045	900	145	11	189	− 55
10–11	27th.	557	135	422	631	1053	900	153	11	194	− 52
11–12	28th.	477	139	338	634	972	900	72	11	183	−122
12–13	29th.	554	134	420	676	1096	900	196	11	181	4
13–14	30th.	530	133	397	751	1148	900	248	11	188	49
14–15	31st.	625	137	488	547	1035	900	135	12	166	− 43

[1]Allowance has been made for the proportion (46.4 per cent) of the protein katabolized assumed to have been excreted in the urine.

[2]It is assumed that the amount of water from fatty tissue is equal to 10 per cent of the fat katabolized.

obtained by deducting the total weight of anhydrous material burned from the total amount of insensible perspiration. The results are recorded in column C of table 62, these values representing the total amount of water actually vaporized from the lungs and skin of the subject. We know from former experience[1] that the preformed water lost in this way is affected largely by muscular activity and that it is made up in part of water which has been combined with flesh and with fatty tissue.

In addition to the loss of water through the lungs and skin, there was also a loss of preformed water through the urine, the amounts being given in column D, while the total amount of preformed water, either vaporized or excreted, is shown in column E. There was, however, not only an outgo but an income of water, as the subject drank a measured amount of water each day. To find the actual loss of preformed water from the store in the body, this income of water (see column F) should be deducted, the values in column G showing the actual loss of preformed water from the store in the body.

The total loss of preformed water varied from 769 grams on the first day to 8 grams on the twenty-third day; as a matter of fact the body actually stored 80 grams of water on the thirteenth day. The heaviest losses occurred on the first few days of the fast. In this discussion it is necessary to consider that the body loses fairly regularly a quantity of protein and fat each day. This loss is accompanied by a loss of the water normally combined in the flesh and fatty tissue, the amount being relatively constant and averaging not far from 200 grams of water per day. The portion of the body remaining (which may, for convenience, be called the "residue") likewise has a water-content which undergoes fluctuation. The total loss of preformed water in column G may therefore be classified under three heads: (1) water of flesh broken down; (2) water of fatty tissue broken down; (3) water from other sources, *i. e.*, from the residue.

The amounts of water from the flesh disintegrated and fatty tissue broken down may be computed by the use of certain factors. Thus it is assumed that there are 4 grams of water combined with every gram of protein to form flesh; furthermore, that body fat is combined with 10 per cent[2] of its weight in water to form fatty tissue. The draft upon the store of preformed water due to the katabolism of protein may therefore be found by multiplying the amount of protein katabolized by 4, and the draft upon the preformed water due to the katabolism of fatty tissue by finding 10 per cent of the amount of fat

[1]Benedict, Carnegie Inst. Wash. Pub. 77, p. 429.

[2]Munk (Lehmann, Mueller, Munk, Senator, and Zuntz, Archiv f. path. Anat. u. Physiol., 1893, **131**, Supp., p. 216) in computing the body-losses uses 10 per cent; Albu and Neuberg (Physiol. u. Path. des Mineralstoffwechsels, Berlin, 1906, p. 9) also assume 10 per cent. On the other hand, Bozenraad (Deutsch. Archiv f. klin. Med., 1911, **103**, p. 120) states that the water-content of human fat may vary from 7 to 46 per cent. The average water-content of the fat in fat people was 13.2 per cent, while in emaciated persons it was 28.2 per cent.

katabolized. These values have been computed and the results are given in columns I and H of table 62. Deducting the amount of preformed water lost through the breaking down of flesh and fatty tissue from the total amount of preformed water lost from the body, we have the preformed water lost from sources other than fat and flesh (column J). It is obvious that the minus signs here indicate an actual addition of water to the residue rather than a loss.

From the figures given in column G, it is seen that the total loss of preformed water from the body in the experiment with L. became less as the fast progressed—that is, there was a tendency to conserve the store of water. This is the more apparent if we consider the figures in column J, which represent the loss or gain of preformed water in the residue. It should be noted, however, that in the computation of these values it was assumed that the proportion of water in the flesh and fatty tissue *katabolized* was not altered during the course of the fast—an assumption which may very properly be made, since the fluctuations in the water-content of the flesh and fat katabolized, as compared with those in the water-content of the whole body, would be so small as to be negligible.

From the figures in column J it will be seen that on the first 5 days of the fast there was a very considerable loss of water from the residue other than that belonging to the flesh and fat katabolized. A period of 5 days followed in which there was an approximate water equilibirum. When the amount of water taken by the subject was increased at the suggestion of Dr. Goodall, there was a retention of water by the residue for some 4 days, thus implying an actual physiological water-need. From that time until the end of the fast, with the exception of 4 days when approximately 50 to 100 grams of water were lost, the store of water showed a distinct tendency towards an addition of water to the residual body-material. From the eleventh to the thirty-first day of the fast there was a positive addition to the storage of water in the residue amounting to 1,383 grams.

This evidence of a retention of water in the body of the fasting man is of especial interest, inasmuch as it is in conformity with other experimental evidence showing a tendency, during fasting,[1] for the flesh to increase in water-content. It has been demonstrated by Abderhalden, Bergell, and Dörpinghaus,[2] however, that there is no change in the composition of the proteid in the body, for, according to the Fischer esterification method, the composition of the fractions does not alter.

[1]Lichtenfelt, Archiv f. d. ges. Physiol., 1904, p. 353; and Sedlmair, Zeitschr. f. Biol., 1899, **37**, p. 25. That the greatest storage is probably in flesh is shown by Engels, Archiv exp. Path. u. Pharm., 1903, **51**, p. 346; other depots are noted by Mayer, Compt. rend. Soc. Biol., 1906, **60**, p. 588, and Paladino, Biochem. Zeitschr., 1912, **38**, p. 443.

[2]Abderhalden, Bergell, and Dörpinghaus, Zeitschr. f. physiol. Chem., 1904, **41**, p. 153.

TOTAL LOSS OF ORIGINAL BODY SUBSTANCE.

From an analysis of the foregoing data we are in a position to state, with a considerable degree of accuracy, the loss of carbohydrate, fat, protein, and preformed water, and solids excreted in urine and from the skin, and thus present a general picture of the total loss of original body substance during fasting. This is shown in table 63. The combustion of carbohydrate ceased after the first 13 days of the fast. The combus-

TABLE 63.—*Distribution of loss, in grams of original body-substance per 24 hours, in experiment wit*

Date.	Day of fast.	Body materials katabolized.				Preformed water lost.			Solid excreta		
		Protein.		Fat.	Carbohydrate.	From flesh (A×4).	From fatty tissue.[2]	From sources other than flesh and fat.[2]	Total solids in urine.[3]	From skin.[4]	F
		Total (N×6.0).	Burned (A×0.536).[1]								
		A	B	C	D	E	F	G	H	I	
1912.											
Apr. 14–15	1st.	42.6	22.8	135	68.8	170	14	585	43.51		
15–16.. ..	2d..	50.4	27.0	142	42.1	202	14′	448	45.38		
16–17.....	3d..	68.0	36.4	130	38.5	272	13	350	50.62		
17–18. ..	4th.	71.2	38.2	136	4.3	285	14	225	56.13	2.20	
18–19	5th.	62.5	33.5	133	15.1	250	13	166	49.09		
19–20.....	6th.	61.1	32.7	133	.....	244	13	11	46.07		
20–21.....	7th.	58.7	31.5	134	.....	235	13	− 65	40.58		
21–22.....	8th.	61.6	33.0	127	4.0	246	13	− 47	44.14		
22–23.....	9th.	64.4	34.5	119	13.5	258	12	− 34	46.81		
23–24.....	10th.	60.3	32.3	120	3.8	241	12	48	42.49	1.52	
24–25.....	11th.	61.5	33.0	115	3.8	246	12	−202	42.05		
25–26.....	12th.	60.8	32.6	118	3.8	243	12	−128	39.21		
26–27.....	13th.	62.1	33.3	111	3.5	248	11	−339	42.01		
27–28.....	14th.	62.6	33.6	117	.....	250	12	−154	40.58		
28–29.....	15th.	50.8	27.2	116	.....	203	12	− 80	32.50		
29–30.....	16th.	57.5	30.8	112	.....	230	11	155	41.12		
Apr. 30–May 1.	17th.	52.9	28.4	112	.....	212	11	67	39.51	1.04	
May 1– 2.....	18th.	49.6	26.6	109	.....	198	11	− 91	35.47		
2– 3.....	19th.	50.2	26.9	109	.....	201	11	7	34.59		
3– 4.....	20th.	46.1	24.7	110	.....	184	11	−180	30.06		
4– 5.....	21st.	47.6	25.5	112	.....	190	11	69	31.88		
5– 6.....	22d..	46.5	24.9	108	.....	186	11	− 2	31.18		
6– 7.....	23d..	43.9	23.5	109	.....	176	11	−179	29.30		
7– 8.....	24th.	48.9	26.2	109	.....	196	11	− 34	32.01	.94	
8– 9.....	25th.	46.9	25.1	109	.....	188	11	− 73	30.32		
9–10.....	26th.	47.3	25.4	109	.....	189	11	− 55	31.04		
10–11.....	27th.	48.4	25.9	109	.....	194	11	− 52	31.52		
11–12.....	28th.	45.7	24.5	114	.....	183	11	−122	29.06		
12–13.....	29th.	45.2	24.2	110	.....	181	11	4	29.64		
13–14.....	30th.	47.0	25.2	108	.....	188	11	49	29.58		
14–15.....	31st.	41.6	22.3	115	.....	166	12	− 43	27.07		

[1]See page 408.

[2]See table 62.

[3]Amounts calculated for first 15 days of fast. (See table 24.)

[4]Urea plus sodium chloride calculated from values given in table 22 (p. 234.) Excreta from the skin determined each week, *e. g.*, from the time of bathing on evening of April 13 to the time of bathing evening of April 20. For the total nitrogen excreted in the urine each day, see table 29.

tion of fat and protein continued without material alteration in relative proportions until the end of the fast. The preformed water lost from the body came from three sources, first, that combined with the protein to form flesh; second, that combined with fat to form fatty tissue; third, water from other sources in the body. Finally, we have the solid excreta from the body made up of the solids of the urine[1] and the solids from the skin. There was no fecal loss.

TOTAL ENERGY LOSS.

The loss in energy as the fast progressed was in two forms, *i. e.*, the kinetic energy in the form of heat, which includes the sensible heat of excreta, the heat lost by radiation and conduction, and the heat of vaporization of water; and the potential energy of the solid excreta, chiefly that of the organic material in the urine.

Considering first the kinetic energy or the heat liberated, it is clear that the heat results from the actual combustion of organic material, such as protein, carbohydrate, and fat. From our former computations (see table 61), we can apportion the heat-production among these three compounds. This apportionment is shown in table 64, which, for subsequent discussion, also gives the total amount of energy lost from the body.

The greatest loss of heat falls upon the fat, with the protein supplying the greater part of the remainder. As a matter of fact, although the carbohydrate (glycogen) is rapidly drawn upon and apparently the available supply is quickly depleted, sufficient glycogen is burned the first day of the fast to furnish somewhat more heat than was supplied by the protein on that day. After the first 3 days, the heat was derived almost wholly from a fat-protein katabolism, with a minimum supply of glycogen. The combustion of glycogen ceases after the thirteenth day.

The actual quota each compound supplies to the daily energy requirement is best seen by placing the heat output subdivision upon the percentage basis. This is done in table 65, which shows that on the first 3 days from 10 to 16 per cent of the heat was derived from glycogen. Subsequently, the glycogen combustion furnished hardly more than 1 to 3 per cent of the heat. After the thirteenth day, approximately 17.5 per cent of the heat was derived from the oxidation of the protein and the remainder from the combustion of fat.

In the fasting experiment with L., the body lost not only the kinetic energy of material burned, but also the potential energy of solid unoxidized material contained in the urine. Since there were no feces during the fast, no potential energy was lost in this way. While both glycogen and fat burn completely to form carbon dioxide and water in

[1]It is obvious that the unoxidized material of protein is a constituent in two columns of the table. In column A, the total protein includes the unoxidized material which appears again in the solids in the urine.

normal katabolism, under certain pathological conditions and in inanition, the fat combustion is defective and certain partially oxidized bodies—the so-called "acetone bodies"—are produced and excreted chiefly in the urine.

In the earlier report of fasting experiments[1] direct evidence of the presence of these bodies was not available, and in computing the heat

TABLE 64.—*Distribution of heat produced per 24 hours to body-materials katabolized, and total energy loss of the body in experiment with L.*

Date.	Day of fast.	Heat produced (calculated).				Energy (potential) of urine.	Total energy loss (D+E).
		From carbohydrate. A	From fat. B	From protein. C	Total (A+B+C). D	E	F
1912.		*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Apr. 14–15	1st	291	1290	188	1769	65	1834
15–16	2d	178	1355	223	1756	89	1845
16–17	3d	163	1238	301	1702	118	1820
17–18	4th	18	1293	315	1626	134	1760
18–19	5th	64	1269	276	1609	123	1732
19–20	6th	...	1267	270	1537	116	1653
20–21	7th	...	1280	260	1540	104	1644
21–22	8th	17	1214	272	1503	116	1619
22–23	9th	57	1139	285	1481	124	1605
23–24	10th	16	1144	266	1426	111	1537
24–25	11th	16	1097	272	1385	110	1495
25–26	12th	16	1125	269	1410	105	1515
26–27	13th	15	1060	274	1349	114	1463
27–28	14th	...	1117	277	1394	111	1505
28–29	15th	...	1107	224	1331	95	1426
29–30	16th	...	1065	254	1319	123	1442
Apr. 30–May 1	17th	...	1066	234	1300	117	1417
May 1– 2	18th	...	1038	219	1257	104	1361
2– 3	19th	...	1039	222	1261	105	1366
3– 4	20th	...	1048	204	1252	91	1343
4– 5	21st	...	1066	210	1276	95	1371
5– 6	22d	...	1030	205	1235	93	1328
6– 7	23d	...	1036	194	1230	88	1318
7– 8	24th	...	1038	216	1254	95	1349
8– 9	25th	...	1044	207	1251	91	1342
9–10	26th	...	1037	209	1246	90	1336
10–11	27th	...	1041	214	1255	90	1345
11–12	28th	...	1087	202	1289	85	1374
12–13	29th	...	1047	200	1247	87	1334
13–14	30th	...	1031	208	1239	87	1326
14–15	31st	...	1097	184	1281	80	1361

from protein we assumed erroneously that all of the unoxidized material in the urine was derived from the cleavage products of protein. The method of simultaneous equations there employed is fundamentally based upon the assumption that the cleavages all proceed in a normal manner. By this method, the total carbon excreted, including that of urine and carbon dioxide, was apportioned among the protein, car-

[1]Benedict, Carnegie Inst. Pub. 77, 1907, p. 495.

bohydrate, and fat on the assumption that the katabolism proceeded in a normal manner. As a matter of fact, inspection will show that while the amounts of carbon, hydrogen, and oxygen employed in the various equations would not be greatly affected in their distribution by this method of computation, the error in apportionment has a theoretical importance which should not be overlooked. If due consideration be shown to these conditions, it will be seen that the method of apportioning the protein, fat, and carbohydrate combustion employed in the present research may be distinctly preferable to that in the earlier publication, although the problem of defective-fat katabolism is only in part theoretically solved by this method.

TABLE 65.—*Proportions of total heat production derived from different body-materials in experiment with L. (Computed per 24 hours.)*

Date.	Day of fast.	From carbohydrate.	From fat.	From protein (net energy).	Date.	Day of fast.	From fat.	From protein (net energy).
1912.		*p. ct.*	*p. ct.*	*p. ct.*	1912.		*p. ct.*	*p. ct.*
Apr. 14–15....	1st...	16.5	72.9	10.6	Apr. 30–May 1.	17th..	82.0	18.0
15–16....	2d...	10.1	77.2	12.7	May 1– 2.....	18th..	82.6	17.4
16–17....	3d...	9.6	72.7	17.7	2– 3....	19th..	82.4	17.6
17–18....	4th..	1.1	79.5	19.4	3– 4....	20th..	83.7	16.3
18–19....	5th..	4.0	78.9	17.1	4– 5....	21st...	83.5	16.5
19–20....	6th..	....	82.4	17.6	5– 6....	22d...	83.4	16.6
20–21....	7th..	....	83.1	16.9	6– 7....	23d...	84.2	15.8
21–22....	8th..	1.1	80.8	18.1	7– 8....	24th..	82.8	17.2
22–23....	9th..	3.8	76.9	19.3	8– 9....	25th..	83.5	16.5
23–24....	10th..	1.1	80.2	18.7	9–10....	26th..	83.2	16.8
24–25....	11th..	1.2	79.2	19.6	10–11....	27th..	82.9	17.1
25–26....	12th..	1.1	79.8	19.1	11–12....	28th..	84.3	15.7
26–27....	13th..	1.1	78.6	20.3	12–13....	29th..	84.0	16.0
27–28....	14th..	....	80.1	19.9	13–14....	30th..	83.2	16.8
28–29....	15th..	....	83.2	16.8	14–15....	31st ..	85.6	14.4
29–30....	16th..	....	80.7	19.3				

It is important, therefore, in considering the total energy loss from the body, to include not only the energy given out as heat and apportioned among the carbohydrate, fat, and protein, but also the amount of potential energy lost in the urine; this potential energy, from the cleavage products of protein and fat, is given in table 64, column E, as derived from the heat of combustion. The entire loss from the body of this fasting man thus represents the kinetic energy of the materials burned plus the potential energy of the solid materials in the urine, this total loss being shown in column F of table 64 for each day of the fast. In general, both the loss in kinetic and total energy steadily decreased as the fast continued and this man lost from his body, in the form of kinetic and potential energy, an average of 1,489 calories per day for 31 consecutive days.

TABLE 66.—*Complete metabolism results with subject L. during 4 days pre-fasting period, 31 days fasting, and 3 days post-fasting period.*

In no series of derived tables is it possible to draw complete comparisons of the various factors of metabolism, and this can be done satisfactorily only when all of the data are grouped together. I have been requested by a number of physiologists to summarize all of the data obtained with this subject in one large table at the end of the book. Since so much stress has been laid upon the desirability of such a presentation, the data are given here in full.

In order to bring together comparative data for each day of the fast, it has been necessary to place in each column results which represent in the aggregate a total of 36 hours, each single result, however, being either taken at the end of 24 hours or representing a total for 24 hours. The results recorded on the thirty-first day to which an asterisk has been affixed were, as a matter of fact, obtained a short time after the first food had been taken.

FIG. 47.—*Metabolism chart of the most important factors measured on subject L. throughout the fast.*

Although table 66 gives the exact mathematical expression of the quantities of materials involved in the different measurements of the metabolism of this subject, a visualization of the relationships between the various factors of metabolism is best secured by a series of curves. A chart containing curves for all of the factors measured on this subject would be of such great size as to preclude convenient inspection. Hence we have collected here only the most important or more generally observed factors. Although no specific reference is made to these curves for any comparisons in the text, it is obvious that a constant reference to this chart is presupposed in a careful reading of the report.